

A PROFESSIONAL'S GUIDE TO PYROTECHNICS

**Understanding
and Making
Exploding
Fireworks**

John Donner

Contents



Introduction	1
Chapter 1: Firecracker History	9
Chapter 2: Tools and Supplies	13
Chapter 3: Chemicals	21
Chapter 4: Chinese Firecrackers	29
Chapter 5: Flash Powder	37
Chapter 6: The American Cannon Cracker	43
Chapter 7: Hitt's Flashcracks	49
Chapter 8: The Cherry Bomb	53
Chapter 9: Ash Cans	59

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Understanding and Making Exploding Fireworks*
by John Donner

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Chapter 10: The M80	63
Chapter 11: The Globe Torpedo	67
Chapter 12: The Cracker Ball	73
Chapter 13: Chasers	77
Chapter 14: The Knallkorper	83
Chapter 15: The Thunder Flash	89
Chapter 16: The Booby Trap	93
Chapter 17: The Triangle Cracker	97
Chapter 18: The Aerial Bomb	103
Glossary	109
Bibliography	115
Further Reading	117
Resources: Chemicals and Supplies	121
Internet Resources	123

Warning



The manufacture, possession, and use of explosives and explosive devices is illegal without certification and registration with the proper authorities. It is solely the reader's responsibility to research and comply with all local, state, and federal laws regarding the manufacture, possession, and use of explosives and explosive devices.

The procedures described in this manual and the resulting end products are extremely dangerous. Whenever dealing with explosives of any type, special precautions must be followed in accordance with industry standards for experimentation and production of explosives. Failure to strictly follow such industry standards may result in harm to life and limb.

Therefore, the author, publisher, and distributors of this book disclaim any liability from any damages or injuries of any type that a reader or user of information contained within this book may encounter from the use of said information. Use the material presented in this manual and any end product or by-product at your own risk.

This book is for information purposes only.

Preface



This report describes briefly the history and manufacture of several varieties of exploding fireworks, including the Chinese firecracker, the cannon cracker, the Hitt's Flashcracks, the cherry bomb, the whistling chaser, the ash can or silver salute, the M-80, the thunder flash, the German Knallkorper, the aerial bomb, the globe torpedo, the cracker ball, and the booby trap. Descriptions of explosive components of display fireworks (saettines, for example) and rocket-propelled explosive fireworks (e.g., Warhead Launchers) have been well described elsewhere in the literature and are not covered in this report. This treatise focuses on simple, hand-fired, noise-making fireworks designed to perform at or near ground level, with the exception of the aerial bomb. This is not a comprehensive work on exploding fireworks, but rather a well-rounded selection of material that covers many of the most popular exploding fireworks used in the United States and abroad during the past century.

Firecrackers and other exploding fireworks remain perennially popular despite attempts by citizen groups and various government bureaucrats to ban their manufacture and use. The simple fact is that a substantial portion of the public continues to enjoy using fireworks of all kinds, including firecrackers. The traditional use of fireworks in connection with patriotic and religious festivities ensures their continued popularity. In addition, the

low technology required to produce most fireworks ensures their continued availability, despite misguided attempts at prohibition.

Limiting availability of firecrackers, especially to young people, unintentionally promotes experimentation with dangerous homemade explosive devices such as bombs made of steel pipe or CO₂ cartridges filled with gunpowder. Furthermore, bans on nonlethal noise-makers encourage the dangerous custom of discharging firearms into the air during celebrations (where is that projectile coming down?).

The technical information provided in this report is complete enough that anyone with a rudimentary understanding of chemistry and the ability to follow detailed written descriptions should be able to reproduce any of the fireworks described. This is not to say that everyone ought to do so. There are certain inherent risks in making any kind of explosive device, even small and seemingly innocuous ones. The methods presented in these pages are less likely to result in unfortunate accidents than are the methods presented in many other publications about fireworks and firecrackers, provided that all indicated safety precautions are followed without exception.

Certain conventions have been observed in writing this book for the sake of convenience and style. The individual sections describing specific items usually begin with brief historical discussions, followed by discussions of construction techniques and ending with safety considerations. Among the grammatical and stylistic conventions is the use of the pronoun "he" in reference to the pyrotechnist, even though some pyrotechnists have been, and continue to be, of the fairer sex. This is not meant to demean, but merely to simplify the style. Also, some of the descriptions assume, for simplicity, that the pyrotechnist is right-handed. It is assumed that those of us who are left-handed will be able to extrapolate and transpose the descriptions for their own purposes. A most important convention is that all formulae are given in terms of mass (weight) and not volume. This practice is standard within the fireworks industry. Some formulae are given in parts, others in percentages, but all refer to measurements of mass.

In every case I have tried to provide accurate, useful informa-

tion and avoid the vagueness, and even outright misstatement, observed in some other publications. Too often those publishing pyrotechnic information for the "quick buck" pay little attention to producing quality work. Some go so far as to reprint ancient or extremely dangerous formulations without even providing prudent warnings or precautionary information. This is not the case in *A Professional's Guide to Pyrotechnics*. It does provide many relatively dangerous formulations, but all come with appropriate warnings and precautions. Take these warnings and precautions seriously.

The historical information in the report is culled from a number of sources, many of which are noted in the bibliography. Some other sources of information desire anonymity because of possible civil or even criminal liability resulting from possible future misuse of this information. This desire has been and will be respected. The intent of laws, the execution of laws, and justice are most often three entirely different things just about everywhere on earth. In the United States we now have protection of our freedom of speech and artistic expression, including writing, under the First Amendment to the U.S. Constitution. However, the Bill of Rights, of which that amendment is a part, has been under attack in the federal courts here for well over a decade. In general, the U.S. Congress and the various agencies charged with law enforcement have sought, usually successfully, to abrogate those rights. Nonetheless, for the time being it is legal in the United States to produce and possess books like this one. *Carpe diem!*

A Professional's Guide to Pyrotechnics was written primarily for distribution within North America, but it will also be shipped overseas. (A good dictionary of American English may help readers overseas to understand the nuances of some of the discussions.) Anyone who attempts to actually construct any of the articles described here would be well advised to obtain any and all permits that might be required by any governmental agency that has an interest in controlling manufacture, use, and possession of exploding fireworks. Regulations vary widely between various local, state or provincial, and national governments. The author cannot be expected to be familiar with the law regarding various aspects of

pyrotechnic practices in every country in the world. Therefore, potential experimenters residing in other countries ought to investigate their own regulatory agencies. At present the Bureau of Alcohol, Tobacco, and Firearms (ATF) is responsible in the United States for regulating fireworks manufacture at the federal level. As of 1990 the ATF was on record as saying that the manufacture of many fireworks at the hobbyist level is not prohibited by current legislation. However, regulations applying to storage, sale, and transportation of fireworks still apply, as do regulations at the state levels. At present, the U.S. government vigorously attempts to eliminate the black market in illegal firecrackers. This means it is not a good idea to sell these items in the United States, ever. The wise hobbyist will do himself a favor and become familiar with all applicable regulations before attempting to duplicate any of the devices described herein. A permit or license anywhere in the world where one is required by law can save much trouble.

An interesting and informative publication, *ATF-Explosives Laws and Regulations*, is available from ATF at the following address:

Bureau of Alcohol, Tobacco, and Firearms
Department of the Treasury
P. O. Box 189
Washington, D.C. 20044-0189

Introduction



Any work subtitled *Understanding and Making Exploding Fireworks* ought to have at least some theory to complement the practice. This section, then, provides a basic theoretical background applicable to most small, exploding fireworks.

Exploding fireworks create their characteristic noises by two kinds of processes, deflagration (rapid burning) and detonation (true high-velocity explosion). As a rule, deflagrating or "low" explosives have much less potential energy output per unit of mass than detonating or "high" explosives.

Typical of a deflagration explosion is a black powder explosion, such as one hears when shooting a muzzle-loading rifle. This explosion is dependent on confinement of the deflagrating composition, in this case black powder, in a relatively strong container. The deflagrating explosion creates a low-velocity shock wave, audible as a loud but low-pitched boom. In fireworks, one often hears this kind of low-pitched boom when shooting old-fashioned Chinese mandarin black powder firecrackers. Many nitrate-based compositions will produce a deflagrating-type explosion when confined properly and ignited. A deflagrating explosion is always the result of what a chemist would call an oxidation/reduction reaction. That is, some fuel or combination of fuels that has a high affinity for a readily available source of oxygen (or a similar element) reduces that source of oxygen. This oxida-

tion liberates heat, light, and chemical reaction products in the process. When such a reaction takes place rapidly enough in a confined space, a deflagrating explosion often occurs.

Detonation, on the other hand, is an explosion characterized by a high-velocity shock wave accompanied by a correspondingly high-pitched cracking or snapping sound. Technically, scientists and technicians who deal with explosives define a high explosive as any explosive in which the shock wave of the explosive reaction travels through the explosive at a rate greater than the speed of sound. A large detonation may make a sound reminiscent of a thunder clap at close range, while a smaller detonation (e.g., that of a silver fulminate "snap-n-pop" firework) may sound like the snap of a high voltage electrical discharge. True detonations can result from combustion processes if the rate of reaction is rapid enough. However, most true detonations are a result of another kind of reaction in which a single substance with an unstable chemical bond (usually a nitrogen-nitrogen bond) breaks down into two or more chemicals with more stable bonding, liberating heat energy and gas under pressure in the process. While chemists describe the nitrogen-nitrogen bonding in these explosives as "unstable," the term as used in this sense should not be taken to mean that high explosives are necessarily more sensitive than deflagrating explosives. In fact, this is usually not the case; most high explosives (e.g., TNT) are more difficult to initiate than low explosives and are therefore more "stable" than an explosive such as black powder. These explosives are known as secondary explosives. Usually, a "primary explosive," a high explosive that detonates from exposure to heat or spark, is required to initiate most "secondary" high explosives. An example of this kind of explosion is a dynamite explosion initiated by a blasting cap filled with lead azide as a "primary" high explosive. Some explosives that usually deflagrate can also be made to detonate. Often, these compositions are among the most sensitive and dangerous of all explosives because of the ease with which a very powerful explosion can be initiated. One familiar example of such a deflagrating/detonating explosive is the composition of potassium chlorate, red phosphorus, and antimony sulfide used in ordinary toy pistol caps. Generally,

detonation of these explosives depends little on confinement of the reactive materials and can occur easily under conditions of little or no confinement.

The majority of modern firecrackers and exploding fireworks use photoflash compositions as explosive charges. Photoflash compositions as a class are characterized by the use of some combination of powdered metal (or metals) along with an oxidizer (or oxidizers) and often other additive substances. (Please see the "Flash Powder" chapter for more detailed information and references.) There appears to be some difficulty with classifying photoflash type compositions as either low or high explosives. So-called "flash and sound" mixtures usually produce a shock wave considerably faster than that of a black-powder-type mixture but considerably slower than that of any of the true secondary explosives. One research paper indicates a velocity of propagation in the neighborhood of 1,300 meters per second for a potassium perchlorate/aluminum flash mixture.¹ Compare this velocity with the figure of 4,450 meters per second reported for TNT in *The Chemistry of Powder and Explosives*.² The 1,300 meters per second figure should be taken as an approximate velocity for a flash explosion arrived at under certain, specific conditions rather than as an exact characteristic for all flash mixtures. Furthermore, the velocity of the detonation is only one criterion used to classify explosive materials; it is not an accurate representation of the total power of an explosive material, but it is a good criterion with which to begin an examination of any explosive.

In order to establish the amount of work performed in a given explosion, it is necessary to consider other factors, such as the amount of gaseous products generated by the reaction and the amount of heat energy released. In the United States, loose flash mixes are legally considered class "A" detonating explosives for purposes of storage and transportation. Yet aerial salutes containing these mixtures are classified as "B" (low) explosives, and small firecrackers as "C" (low) explosives. Flash and sound mixtures actually have characteristics of both deflagrating and detonating explosives and probably ought to occupy a third category altogether. Flash mixtures can explode with no confinement and be initiated by flame,

friction, heat, shock, or spark. Initiation of flash mixtures with primary explosives markedly increases their velocities of detonation.

The characteristics of the compositions used to produce exploding fireworks affect the performance of the finished products. The pyrotechnist can select the type and amount of composition to use and the degree of confinement to produce a design that will produce an explosion ranging anywhere from the tiniest "snap" to a moderate "bang" to an ear-splitting "crack." He can produce a low-pitched "boom" or the high-pitched report of detonation and have a pretty good idea of what kind of results he is going to have before ever lighting the fuse. The wise pyrotechnist, however, remembers that every batch of chemicals is different, and no two batches of composition will behave identically.

The larger the firecracker, the easier it is to produce a mixture that will explode, and the less one must be concerned about the particle size and shapes of the component chemicals, the homogeneity of the mixture, and the attention paid to getting the optimal proportions of the components. Conversely, the smaller the firecracker, the more careful one must be about using a composition that contains a homogenous mixture of quality materials. The smaller firecrackers will generally require hotter (i.e., more rapid-burning) mixtures than the larger ones. In fact, since the hotter compositions also tend to be the most dangerous to handle, they are best used in very small fireworks and in fireworks like the whistling chaser, where one may want to produce an explosion from an open-ended tube.

Anyone with training in chemistry can quantify (roughly, anyway) the amount of energy released in an explosion by comparing the bonding energy of the reactants (that is, the components of the explosive) with the bonding energy of the reaction products (the by-products of the explosive reaction). The difference in the bonding energies tells us the total amount of energy released. The amount of energy released divided by the time the reaction takes to proceed from start to finish will reveal the shock wave strength of the explosion (that is, the speed of the impulse or brisance).

Experimenters without advanced chemical training can learn by experience, practicing with small quantities of pyrotechnic mixtures

to get a feel for their different characteristics. When one is experimenting with high-energy materials, it is important that he keep those quantities small.

Another rule of thumb worth knowing is that the amount of energy of an explosion varies inversely with the cube of the distance from the explosion. In other words, the amount of energy applied to anything within the vicinity of an explosion decreases proportionally to the cube of the distance. Thus, the energy of an explosion 6 feet away will have 1/216th the power of an explosion 1 foot away under ideal conditions in the open air. Therefore, one has a much greater chance of losing a hand or fingers if a large firecracker goes off in the hand than one does if it goes off at the distance of, say, a lit stick of punk. Hence the old Chinese proverb: "DO NOT HOLD IN HAND" that appears on so many firecracker packs.

Finally, here is a list of safety precautions that every experimenter should adhere to religiously. These rules are not the last word in safety, but they do point in the right direction. Many of these observations and suggestions convey valuable information best learned early in the career of every pyrotechnist. A good education can be the pyrotechnist's best defense against disaster.

BASIC PYROTECHNICS SAFETY PRECAUTIONS

*There are old pyros,
and there are bold pyros,
but there are not very many
old, bold pyros.*

—author unknown

1. The wise pyrotechnist always uses tubes and containers of paper and cardboard for fireworks; he never uses tubes or containers of metal or other hard materials. Confetti is less lethal than shrapnel.
2. The wise pyrotechnist always wears adequate eye and respiratory protection when working with any pyrotechnic compositions.

3. The wise pyrotechnist always experiments in an appropriate place, away from other people and property, with fire extinguishing equipment nearby.
4. Cleanliness is next to Godliness. The wise pyrotechnist keeps his work area clean and neat. He keeps his tools clean. He cleans up all chemical spills immediately.
5. The wise pyrotechnist always uses nonsparking tools. He scrupulously avoids the use of iron and steel as one would avoid the plague.
6. The wise pyrotechnist treats all pyrotechnic compositions gently and carefully. He avoids friction and shock when working with pyrotechnic compositions.
7. The wise pyrotechnist grinds only one chemical at a time. He never grinds potassium chlorate ($KClO_3$) with any other chemical!!! (And he scrupulously cleans grinding and mixing equipment between uses for different chemical compounds.)
8. The wise pyrotechnist avoids using electrical tools and devices around explosives and pyrotechnic materials. One small spark can cause much grief.
9. The wise pyrotechnist does not smoke. Smokers should get another hobby. At the least, the nonsuicidal pyrotechnist never smokes around pyrotechnic materials. He leaves matches and tobacco elsewhere before entering the work area.
10. The wise pyrotechnist doesn't skimp on the fuse. He uses a good quality American-made visco fuse, or an American or Japanese timing fuse (for appropriate applications). The wise pyrotechnist avoids using the cheaper grades of fuse because they are often not safe. Another old cliche says, "Better to have a fuse a foot too long than an inch too short." The beginner leaves

black match and quick match to professional, trained pyrotechnists. Paper firecracker fuse ought to be used only for small firecrackers.

11. The wise pyrotechnist always stores fireworks carefully in a securely locked cabinet or magazine and away from living areas. The best course is to make up only as much material as will be used in the near future, and refrain altogether from storing quantities of live salutes. Often paper tube and fuse assemblies can be made up ahead of time so that they can be loaded quickly just prior to use without the dangers associated with storing live materials. The wise pyro considers what could happen in the event of a fire, or in the event that some local juvenile delinquent burglarizes his storage cabinet and subsequently gets caught with the stuff.
12. The wise pyrotechnist stores chemicals carefully. Oxidizers should be stored in a separate cabinet from fuels. Acids should be stored on the bottom shelf in their own cabinet. Never store acids near oxidizers. This holds especially true for chlorates, which can be inflamed or detonated by contact with acids.
13. The wise pyrotechnist loads compositions from a covered container, closing the container before moving on to the next step in the operation.
14. The wise pyrotechnist avoids static electricity at all costs. He mixes flash compositions on humid days and makes liberal use of antistatic spray and avoids synthetic or silk clothing.
15. The wise pyrotechnist is wary of introducing water into mixtures containing metal powders. Compositions containing some metals, such as magnesium and zinc, can ignite on contact with water.
16. The wise pyrotechnist educates himself about the nature of the materials he works with before mixing up even a gram of composition.

I think this covers most of the points I wish I'd had learned before I began working with firecrackers and the like. However, this merely touches the surface. The wise beginner will do some more research before starting out. For more in depth discussion of theoretical aspects of pyrotechnics, Tenney Davis's *Chemistry of Powder and Explosives* and Takeo Shimizu's *Fireworks: The Art, Science and Technique* are good references. Refer to the suggested reading list and bibliography at the end of this treatise for additional sources of information.

ENDNOTES

1. J. Henfkowitz et al., "Combustion in Loose Granular Mixtures of Potassium Perchlorate and Aluminum," Eighth Symposium (International) on Combustion. (Baltimore, Williams & Wilkins Co.: 1962).
2. Tenney Lombard Davis, *The Chemistry of Powder and Explosives*. (New York: John Wiley, 1943) 232.

Firecracker History



Firecrackers are, without a doubt, one of the older varieties of fireworks, although published historical records do not reveal exactly when firecrackers were invented. Probably the only older fireworks are the fountains and the ground rats made in China hundreds of years ago.

The Chinese invented firecrackers and remain the masters of firecracker making. Originally, firecrackers were made from bamboo tubes filled with a crude black powder mixture; that is, a mixture of either potassium or sodium nitrate along with charcoal and sulfur. The fuses of these devices were supposedly made from hemp fibers impregnated with black powder, similar to the "black match" fuse of modern pyrotechnists. Bamboo tubes are usually quite hard, composed of tough cellulose fibers strengthened with silica. In fact, fresh green bamboo tubes will explode very loudly when thrown into a fire from the buildup of steam pressure—without containing any explosive powder at all.

However, the firecrackers with which we are familiar are more recent inventions. These are made from rough paper tubes, filled with some explosive powder and closed at the ends with either a crimp or a clay plug. The traditional Chinese firecracker is filled with black powder and closed at the ends with clay. In the Far East, the popular variety is the "mandarin" cracker, made from an all red paper tube that is said to scare away devils or

demons when it explodes. A similar product made with a crude, often recycled paper tube has been exported widely.

The use of chlorates and then perchlorates profoundly changed firecracker manufacture during the 19th century. Chlorate- and perchlorate-based explosive powders gave far more punch to exploding fireworks than the nitrate black powder used previously. Fireworks companies in the United States wanted to compete with the cheap, imported Chinese firecrackers but had difficulty doing so because of the difference in labor costs between China and the United States. So they developed large firecrackers—American cannon crackers—that used chlorate-based powder and were sold in sizes ranging up to a foot long or more! These dangerous items became both boon and bane to the fireworks industry. For a time the cannon crackers made good money for fireworks firms, but at the cost of bad publicity from the many serious accidents that occurred with them. The state of medical care at the time, coupled with the rise of "yellow journalism," affected the negativity of the publicity associated with the firecracker business. At the turn of the century, what we would today consider a "minor" injury would often end with death or lifelong disability. These problems were exploited by the press, whether in good faith, or simply because then, as now, the sensational sold news.

Around the turn of the century another significant development occurred in firecracker manufacture. Westerners introduced the use of photoflash compositions into fireworks manufacture at home and overseas; these were the same kinds of powders photographers used for illumination prior to the development of the more modern flash bulbs. Some have attributed this development to the Hitt family of Washington, which manufactured the famous "Hitt's Flashcrackas." It is far from clear, though, who first used photoflash compositions as explosive charges in fireworks, let alone who introduced the practice to the Chinese. In any case, the introduction of metal-fueled flash powders, known simply as "flash" in the industry, revolutionized firecracker manufacture. Overnight, smaller firecrackers became more potent and therefore more dangerous.

The 1920s were the heyday of the firecracker business. Improved technology combined with increased disposable income

to form a boom economy, and an incredible variety of firecrackers was manufactured and sold. However, the Depression of the 1930s and World War II disrupted the firecracker industry greatly. First the economy collapsed, and the discretionary income that fueled the firecracker business nearly disappeared. By the time the economy was recovering, World War II interrupted trade with the Far East. The Chinese firecracker trade was a part of that business. Furthermore, many fireworks manufacturers switched to producing war materials and never returned to producing civilian fireworks. Legislation was passed that prohibited the old giant cannon crackers. Taxes assessed on the imported crackers effectively limited their size to less than 2 inches in length.

There was a brief resurgence in the firecracker business during the 1950s and 1960s, but by then the antifireworks lobbies were ascendant, and the firecracker business seemed under attack from all sides. The mid-1960s saw firecrackers reduced in size again to a maximum powder load of 2 grains (130 milligrams). In the 1960s and 1970s, antifireworks legislation passed at the federal level severely crippled the domestic fireworks industry—at least the part that produced firecrackers and other "family" fireworks. Normalization of relations with the People's Republic of China by the Nixon administration in the early 1970s flooded the fireworks market with incredibly cheap Chinese fireworks, and there was just no way for domestic producers to compete effectively. The U.S. government in 1977 further reduced the maximum load in firecrackers to a tiny 50 milligrams. Thus, from the 1970s on, small, "consumer" fireworks—that is, "Class C" goods—have been made predominantly (again) by the Chinese.

While many inside the fireworks community blame the "liberals" for passage of restrictive fireworks legislation, the fact is that the business doesn't seem to have fared much better in the last decade under the conservative Reagan and Bush administrations. American government just seems to have a prohibition mentality, to which the fireworks business has fallen victim.

The illegal fireworks business presents so many opportunities for the criminal entrepreneur that it is also doubtful that the govern-

ment will ever effectively prohibit the firecracker business. At present the business in illegal firecrackers and ever more gigantic flash salutes is more prevalent in the weeks before July 4 than it ever was before the crackdown on the old M-80s and cherry bombs. Some individuals close to the fireworks business maintain that the ban on large salutes has inadvertently promoted the use of large flash bombs by the general public. Total prohibition seems to have eliminated all restraint among the black marketeers. The largest and most dangerous of the bootleg firecrackers and flash bombs are, not coincidentally, most available and most widely distributed in states and cities that have enacted total fireworks prohibitions.

The hobbyist will find, as he reads this treatise, that firecrackers and exploding fireworks of all sorts are relatively simple to make. Most are relatively safe to produce if the maker adheres to proper safety procedures. Of course, "the authorities" often dispute this. But then, they are law enforcement bureaucrats and not usually experienced pyrotechnists. Still, it is best to check one's sources, get educated about the processes and procedures, and avoid materials published by fast buck artists who are wholly unconcerned with safety considerations. Many people of questionable background have written and published much material that deals with homemade fireworks and explosives. Often this documentation contains serious errors and omissions that can cause serious accidents. Some of these publications are highly touted by certain mail order firms and are sold in great quantities. A good example of such a dangerous manual is *The Poor Man's James Bond*; yet another is *The Anarchist Cookbook*. In recent years, the Internet has provided a large amount of questionable information about fireworks and a little good information as well. *Caveat emptor* (let the buyer beware!), the Romans used to say.

Tools and Supplies



Firework making requires the use of a selection of specialized tools. Some of these can be made easily in a home workshop. Others can be bought through chemical supply houses, pharmacies, or other commercial sources. Basic chemical lab ware can often be found at large colleges and universities through their surplus property disposition facilities. Art supply stores can often supply specialized papers and cardboard, as well as decorative materials like paints. There are several toolmakers who cater to the fireworks trade, and they advertise in most of the trade publications.

Balance scale—Some kind of scale, accurate in weighing small quantities of materials, is a must. For general use I have found the triple beam laboratory balance to be without parallel. Some people prefer a powder balance such as gun enthusiasts use for reloading cartridges. However, for simplicity, reliability, and ease of use, a student-grade lab balance like the Ohaus is probably best. Electronic balances are neat but tend to be temperamental, expensive to buy, and relatively expensive to maintain. Spring scales are notoriously inaccurate.

Blender—The kitchen blender, or similar device such as a coffee grinder, can be used for pulverizing many chemicals. However, the wise

pyrotechnist carefully cleans the blender after each use in order to ensure that his ground chemicals remain free of contaminants and be certain that no unwanted mixture is produced during the grinding process. Because of the potential for accidental ignition from impact or electrical discharge, whether static or from the motor, blenders are never used for mixing dry pyrotechnic compositions!

Corks—Natural corks, the old-fashioned ones made from cork tree bark, make good end plugs for some kinds of fireworks. In earlier decades they were extensively used for this purpose, but because of their expense, corks are not often used for this purpose now. Corks are light in weight, soft, and very well-suited to this purpose. Of course, synthetic rubber or plastic "corks" are not well-suited for these purposes, since they are hard, dense, and make relatively dangerous flying projectiles.

Fuse—Several kinds of fuse are used in fireworks making. The best kind for making firecrackers today, as well as for many other applications, is known as visco safety fuse, also known as green safety fuse, cannon fuse, safety wick, and so forth. This is a black powder fuse covered with a thread wrapper and one or more layers of nitrocellulose lacquer. This fuse comes from several different manufacturers in several countries. To date, the best visco fuse in a $\frac{1}{8}$ " class "C" grade is made by the American Visco Fuse Company of Gibraltar, Michigan, near Detroit. The worst is made by the People's Republic of China; it is absolute junk. Time fuse for aerial bombs comes in many varieties. The best ones are the Rotzi $\frac{1}{8}$ " time fuse and the Japanese $\frac{1}{8}$ " time fuse. The worst time fuse has been a Chinese one similar in appearance to the Rotzi fuse but very much prone to failure. Ensign Bickford makes a blasting safety fuse similar to the Rotzi fuse that is very good but difficult to get, since Bickford will not sell it to fireworks companies. Remember, the wise pyrotechnist doesn't skimp on the fuse; he takes the time and trouble to get good fuse. Also, he is aware that time fuses such as the Japanese time fuse burn internally. It is usually difficult to determine by

visual inspection whether or not they are lit and burning, and so they are more dangerous to use for many applications than a safety fuse that burns externally.

Fuse cutter—There are several designs available in the published pyrotechnic literature for devices intended to cut fuses quickly, safely, and with minimal trouble and expense. A good fuse cutter will save the wise pyrotechnist much time and work.

Gloves—Gloves of several sorts are useful to the pyrotechnist. When one is working with toxic or irritating chemicals, disposable latex rubber or plastic gloves can be useful. For lighting fireworks, heavier gloves can be a good safety precaution. Kid leather gloves are good protection for lighting fireworks and also allow for freedom of movement and good tactile sensation.

Glues and adhesives—The oldest glues used in fireworks making in decades past were the starch-based glues and pastes and the hide glues made from animal carcasses. These still work well for many pyrotechnic applications, and they lend an air of authenticity that may be lacking if modern, synthetic-based glues are used. Ordinary wallpaper paste made from wheat starch with the optional addition of sodium silicate solution works well for rolling cases and is cheap. Some pyrotechnists prefer so-called "vinyl wallpaper paste" for case rolling.

Poly Vinyl Acetate (PVA), also known as "white glue," like Elmer's, works even better for many applications but is expensive and obviously anachronistic when historic authenticity is sought. Where neither expense nor authenticity are concerns, PVA plastic-based glues are often useful in many pyrotechnic applications. Some pyrotechnists have reported problems when they have used PVA glues to glue fuses into cases; it seems the glue can penetrate the fuse core and damage the fuse. Other glues are less subject to this problem.

Hide glue comes in many forms, both prepared liquids and solid chunks for heat application. Franklin's Hide Glue works well for many applications where an animal glue would have been used in decades past.

Epoxy resin glues are outstanding for applications like gluing mortar tubes on bases where great strength is required.

Hot-melt glue remains popular for certain applications. A petrochemical product applied with a special gun dispenser, hot melt glue works well for binding porous materials, but one must exercise care when using it in the pyrotechnic workshop because, first, it is applied hot, and, second, the dispenser guns are electrical appliances with all the hazards electricity brings to pyrotechny.

Silicate/carbonate adhesive was popular in the fireworks industry in the 1950s and 1960s for making end plugs in salutes. This material usually didn't stand the test of time and often crumbled in storage. However, for history's sake, the material is made by adding thick sodium silicate solution to precipitated chalk (CaCO_3) until a heavy creamlike consistency is achieved. It must be used quickly because it sets up like cement rather than drying like most glues. Some of the old-time pyrotechnic manufacturers (in the late '60s and early '70s) would dispense this cement from plastic squeeze bottles, such as those sometimes used for dispensing catsup in cheap restaurants.

Jigs—A tool known as a jig is sometimes useful or necessary to hold tubes, cup sets, or unfinished fireworks in position while filling or performing some other operation upon them. Often such a jig can be made by drilling holes in a board with a drill press. The holes will accommodate a particular diameter of tube, or tubes can be supported upright from the inside if dowels or metal rods are set in the board.

Paintbrushes—Paintbrushes can be very useful in the pyrotechnist's workshop. Larger ones can be used to apply glue or paste to

paper while making tubes. Smaller paintbrushes with natural fiber bristles can be used to stir flash powder and other pyrotechnic compositions. For mixing compositions, any exposed metal parts of the brush ought to be covered with masking tape or other protective covering to ensure against causing sparks. Paintbrushes should be cleaned after each use with Ivory soap and rinsed with water. This will both help remove residue from the mixing and leave a static-inhibiting coating on the brush fibers. (Because Ivory is a real soap and not a synthetic detergent, it helps prevent static build-up in the fibers of the brush, whereas detergent often exacerbates the problem.) Plastic brushes should be avoided for use in mixing compositions, since the plastic fibers create a static hazard.

Paper—The pyrotechnist makes use of many papers and paper products in his pursuits. In centuries past, all materials had to be made from scratch or reused and recycled. In fact, pyrotechnists may be among the oldest groups of recyclers. John Bate, for example, wrote in his 1635 book on firework-making that old law books provided the best paper for making rocket cases—a noble and entirely fitting use for legal texts, as well as being more ecologically sound than using virgin paper. Today we use many kinds of paper in our work. Kraft paper, a relatively crude but strong paper made from wood pulp, is often used to make tubes, end plugs, and disks. Kraft is made in many thicknesses, or "weights." Grocery bags, for instance, are often made from a medium- to medium-heavy kraft paper (50#-80#) that can be very useful in tube making. A lighter weight kraft paper (e.g., 30#), such as that commonly used in small lunch bags or other small bags used by shopkeepers, is useful when more delicate operations are called for, such as making flash bags for Flashcrackas. Gummed kraft paper tape is very useful because it minimizes the need to use adhesives in tube rolling and because it is available already cut to sizes often useful to the pyrotechnist. There are many kinds of tissue paper; some are useful for decorative wrapping. More importantly, handmade Japanese tis-

sues find use in fuse making and as parachutes in some aerial fireworks. Probably the most useful tissue is a Japanese variety called Ganpi or Gampi, which is very strong both dry and wet because of its long, tough fibers. Glassine paper, such as stamp collectors sometimes use for packaging stamps, substitutes for the translucent rice paper that traditionally serves for packaging Chinese firecrackers. Decorative papers such as gift wrapping papers and colorful origami papers can easily beautify an otherwise drab paper tube. The inventive pyrotechnist can use many kinds of waste paper with a little imagination—we were recycling long before it became fashionable.

Powder scoops—Many kinds of powder scoops are used by pyrotechnists. At the time of this writing, sets of plastic powder scoops made for reloading rifle and pistol cartridges were sold for less than \$10. For this paltry sum, the pyrotechnist gets a set of scoops that ranges in size from 0.3 cc up to 4.3 cc in increments of 0.2 to 0.4 cc. This set of tools lends itself well to many tasks in pyrotechny.

Presses—A press is a very handy tool for the pyro workshop, especially if the artist ever wants to make whistles or rockets. A large 3-ton arbor press with a moveable head performs quite well for loading whistles and other kinds of fireworks, such as skyrockets. However, many experienced pyrotechnists swear by hydraulic or pneumatic presses. Using a press has many advantages over ramming with a mallet, including consistency of results and reducing hazard from shock and impact.

Respirator—A good respirator is a must when working with pyro chemicals, especially metal powders and toxic materials. The wise pyrotechnist avoids the cheap, disposable, nuisance dust respirators; instead, he uses a good quality model such as a Bink's respirator with replaceable filtration units. Some pyrotechnists prefer full-face protection that integrates a respirator and shock-resistant face shield.

Rock tumbler—A rock tumbler such as lapidary enthusiasts use for polishing stones makes a good ball mill for grinding chemicals and mixing some pyrotechnic compositions. Usually this process is accomplished by tumbling the chemical(s) with the addition of some grinding medium such as brass or lead balls or specially designed ceramic grinding balls or cylinders. The grinding medium tumbles in the tumbling jar along with the chemical(s), crushing any softer material that falls between two pieces of the tumbling medium. The wise pyrotechnist avoids grinding pyrotechnic mixtures that are likely to explode from friction or impact (such as flash powder)!

Sieves—These are important for mixing compositions. There are sieves commercially available from ceramics suppliers that work well. Sieves are described according to mesh size. (There is a variety of standards for sieve mesh sizes around the world, but the American standards are used in this text.) While it is not exact, one can think of the sieve mesh number as the number of openings per linear inch in the sieve surface. For instance, a square-inch surface of a 20 mesh sieve, under the American system of classification, will have 20^2 or 400 openings in each square inch; the higher the number of the sieve, the smaller the openings in the screen. Sieves for mixing powders should be in the 20-40 mesh range as a rule and be made of brass, bronze, or other nonsparking metal. Ordinary steel screen sieves are not suitable for pyrotechnic use since they are a spark hazard. Stainless steel can be used for some purposes where corrosion resistance is a consideration, but it can cause sparks, as when hit with ceramic grinding media.

String—Good quality string has many uses in pyrotechny. The Chinese often use hemp fiber, which is now difficult to come by in the West. American and Italian pyrotechnists tend to favor flax twine for many applications because of its exceptional strength. However, a good quality cotton or cotton/polyester string can be used for many of the applications described here.

Chemicals



For many pyrotechnists, obtaining reliable supplies of chemicals can present problems. At present, several chemical suppliers will sell technical grade chemicals to any adult who chooses to seek them out. Often, the wise pyrotechnist can find reliable sources of chemicals through groups such as the Pyrotechnics Guild International and through advertisements in publications such as *American Fireworks News*. Many chemical suppliers will ship overseas, but it is the responsibility of the buyer to make certain the material purchased can clear Customs.

For most fireworks making, technical grade chemicals are quite adequate. However, for safety's sake, the purer the chemicals, the better. Long treatises have been written about various chemicals and grades of chemicals, specifically pertaining to their use in fireworks making. Here is some information and a few pointers on the chemicals used in the procedures described in *Big Bang Theory and Practice*. Many, if not most, pyro chemicals are toxic to some degree. The wise pyrotechnist treats them accordingly and takes responsibility for preserving his health. For further information, refer to John Conkling's *Chemistry of Pyrotechnics*, and Davis's *The Chemistry of Powder and Explosives*.

Accroides resin—Also known as "red gum," accroides resin is a natural plant product popular for use as a binder and/or fuel in many

pyrotechnic compositions. It is soluble in most alcohols and other nonpolar solvents, but not in water.

Aluminum powder [Al]—Aluminum powder comes in many grades and varieties. These are usually designated by particle size, shape, and sometimes by a trade name, brand name, or code number. For use in smaller exploding fireworks, the best grades generally are 400 mesh or smaller. The best particle shape is flake, because this has the greatest surface area. Absolutely the most powerful grade of aluminum is known as German black or German dark. Two firms in Germany manufacture this aluminum under the trade names Black Head and Gloria. Some American firms make a class of aluminum powder known as American dark pyro grade that is usually about 400 mesh and works quite well, but not so well as the German black. One well known kind of American dark is the 809 made by Reynolds or Alcoa. The Germans make a variety known as "Blue Head" that is roughly equivalent to the American dark in quality. Aluminum powder is also made in granular and spherical particle shapes, which are next-to-last and last resorts, respectively, when making exploding fireworks. Aluminum dust is a known health hazard; when breathed it can damage the lungs. Also, some medical researchers believe that aluminum intake is related to the development of Alzheimer's disease. Respirator use is indicated.

Antimony [Sb]—Antimony metal is called for in many antiquated pyrotechnic formulations. At present, powdered antimony is difficult to obtain in the United States due to its regulation as a toxin. In the days before aluminum and magnesium could be produced inexpensively, antimony metal provided a metallic fuel source for many pyrotechnic mixtures. Antimony reacts less violently with oxygen than do either aluminum or magnesium. However, antimony and its salts are toxic; caution and the use of protective clothing are indicated when using antimony or any of its salts (see **Antimony sulfide**).

Antimony sulfide [Sb₂S₃]—Antimony sulfide is supplied in two varieties: the black trisulfide known as stibnite or "Chinese needles" to mineralogists and the orange-colored pentasulfide [Sb₂S₅]. For use in fireworks, the black trisulfide of at least 350 mesh or finer should be used. For use as an additive in flash, the common 200 mesh "Chinese needles" will do. Antimony salts are toxic, as are most heavy metal salts. Respirator use is indicated. Also, the smoke from antimony-based compositions is toxic.

Arsenic disulfide [As₂S₂]—Also known as "realgar," arsenic disulfide is an orange-colored salt of the heavy metal arsenic, used in making "cracker balls" and in some smoke compositions. The best grade comes from Japan. Because of its toxicity, this material is regulated by the EPA and is increasingly difficult to find in the United States. The wise pyrotechnist uses gloves and a respirator when working with realgar.

Barium nitrate [Ba(NO₃)₂]—Barium nitrate is sometimes used in flash mixtures as a substitute for potassium perchlorate. It produces a good quality flash less sensitive than perchlorate flash. But there is a trade-off in that barium nitrate is quite toxic. Since it can be absorbed directly through the skin, especially when mixed with perspiration, gloves and respirator are indicated.

Charcoal [C]—The best charcoal powder for use in fireworks is probably willow charcoal. However, charcoal sourced from a soft maple or cottonwood will also work fairly well. The pyrotechnist avoids pine charcoals and those sourced from very hard woods, except for certain specific applications that call for them. Charcoal powders made commercially are graded according to size in mesh sizes ranging from greater than 20 mesh (coarse) all the way down to air-float (AF) grade that is a very fine, dustlike powder.

Clay—Powdered clay is often used in fireworks to plug ends of tubes. Many kinds of clay are suitable for this use. One good kind is called Hawthorne Bond and is available from many ceramics suppliers. Clay can be used as it is supplied, or it can be treated with a small amount of wax (less than 1 percent, either added as a powder or dissolved in a solvent such as hexane, mixed with the clay, and allowed to evaporate off) to improve its cohesion, especially if the fireworks will be stored for long periods and/or fired in sub-freezing temperatures.

Dextrine—Dextrine (or dextrin) is a chemically modified starch powder used as an adhesive binding agent and as a fuel in many pyrotechnic mixtures. There are two varieties of dextrine that find use in pyrotechny—white and yellow. By far the most common and useful is the yellow variety that is made commercially by heating powdered potato starch until it pyrolyzes. During this process, the white starch powder changes color to a distinctive brownish yellow. Dextrine is soluble in water but not in alcohol. Dextrine should not be confused with the sugar, dextrose, which is a very different chemical.

Iron oxide [Fe₂O₃]—Iron oxide, common rust, is sometimes used as a catalyst to aid the breakdown of chlorates or perchlorates in much the same way that manganese dioxide is used.

Manganese dioxide [MnO₂]—Manganese dioxide is a black crystalline powder used to catalyze the decomposition of chlorates and perchlorates in caps and torpedoes. It is nontoxic but increases the sensitivity of compositions containing chlorates and perchlorates by lowering the amount of energy required to ignite them.

Phosphorus, amorphous [P₄]—Also known as red phosphorus, amorphous phosphorus is an elemental chemical used in fireworks, primarily in the manufacture of toy pistol caps and formerly in certain torpedoes and other impact-sensitive devices.

Compositions produced with this chemical are to be approached with the greatest of caution. Red phosphorus is very reactive and forms compositions of the greatest sensitivity. One should not confuse red phosphorus with her even nastier sister, white (yellow) phosphorus. Compositions containing phosphorus must be handled wet, and in the smallest possible quantities.

Petroleum jelly—This is sometimes used as a component of whistle compositions that use hygroscopic fuels, such as sodium salicylate. It seals the otherwise water-absorbing crystals and also lubricates the mixture, aiding its safe compaction.

Prime—Many applications require that fuses be primed, that is, coated with a flammable mixture to ensure ease of ignition. Many kinds of prime can be used, but one good kind is known as nitrocellulose/black powder prime. This is made by mixing mealed black powder with nitrocellulose lacquer. Nitrocellulose lacquer, also known as n/c lacquer in the trade, is usually supplied as a 10-percent mixture in acetone or other thinner. The finished prime should contain about 2-percent to 3-percent nitrocellulose in the finally dried priming mixture. The mixture will need to be thinned with acetone as needed while preparing and while using, since the acetone evaporates very quickly. The pyrotechnist weighs the components out after calculating how much lacquer will be required for a given amount of meal powder. He pours the mixture into a suitable container—polyethylene containers work well—and thins to the consistency of a thick soup with acetone. Fuse ends can then be dipped into the mixture to prime them. This mixture needs to be stirred frequently to maintain its homogeneity.

Potassium chlorate [KClO₃]—Potassium chlorate is one of the most useful oxidizers in pyrotechny. However, compositions made with it tend to be much more sensitive than those made with nitrates or perchlorates. Potassium chlorate is relatively nontoxic in small quantities and is moderately soluble in water.

The best technical grade of potassium chlorate at present comes from Sweden, where it is electrolyzed with the hydroelectric power so abundant in that part of the world.

Potassium nitrate [KNO₃]—Also known as "saltpeter," potassium nitrate is the oldest known oxidizer used in pyrotechny. For use in black-powder-type compositions, even the coarse agricultural grade of nitrate is adequate and extremely inexpensive. It is relatively nontoxic in small quantities.

Potassium perchlorate [KClO₄]—Also known as "perc," potassium perchlorate is one of the most widely used oxidizers in pyrotechny. For many applications it is preferred over the chlorate because of its much wider margin of safety. Consequently, it has a better reputation among many pyrotechnists. Unfortunately, the perchlorate is simply not suited for some applications, such as caps and torpedoes.

Silica [SiO₂]—Commonly known by the trade names Cab-O-Sil and Aero-Sil, fumed silica dust is often used as an additive for flash powders to increase the strength of the mixture. The function of fumed silica is to keep flash fluffy and free flowing, enhancing flame propagation through the mixture. Fumed silica is used in the tool and die industry as a mold-release agent. It comes as a fluffy white crystalline powder that floats easily in the air. Fumed silica is not toxic or explosive, but it is hazardous to breathe, similar in many ways to asbestos dust. Respirator use is indicated when working with fumed silica.

Sodium salicylate [NaC₇H₅O₃]—Sodium salicylate is a white crystalline powder, chemically related to both aspirin and menthol. It is quite hygroscopic; that is to say, it has a marked tendency to absorb water from humid air. Sodium salicylate is used as a fuel in some varieties of whistling fireworks. The ideal particle size seems to be a nominally 200 mesh powder, all passing 180 mesh and retained on 220 mesh. Sodium salicylate must be dry

to function well in these devices. When wet the powder can be heated by itself to 250°F to dry. Dried sodium salicylate should be stored in airtight containers.

Sodium silicate [Na₂Si₃O₇]—A solution of sodium silicate in water (water glass) is commonly used as a component of several pyrotechnic adhesives, including some used for plugging tubes and also as an adhesive for making the agglomerated finishes of cherry bombs and globe torpedoes. Solutions of sodium silicate are commercially available in many concentrations; the higher the percentage of sodium silicate in the solution, the more viscous (thick) it will be. For use as a pyrotechnic adhesive, the concentration should be at least 20 percent and not more than 40 percent. Sodium silicate solution is often available in well-stocked pharmacies or hardware stores, where it may be called either water glass or egg preserver.

Stearin [C₂₁H₄₂O₄]—Stearin is a waxy, organic compound used as an aid in producing metal powders and sometimes as a fuel in pyrotechnic mixtures.

Sulfur [S]—Sulfur is a widely used fuel in pyrotechny. The best grades for making fireworks are those "sulfur flours" made for the tire and rubber industry. New batches of sulfur should be tested for residual acidity, which can be dangerous in many pyrotechnic applications. Acidic sulfur (for example, "flowers of sulfur") can be buffered with magnesium carbonate (≤ 1 percent) to relieve this acidity.

Titanium [Ti]—Finely divided titanium is sometimes added to flash powders in order to give bright sparks with the explosion of aerial salutes. The best grades for this are granulated or sponge powders around 20-40 mesh. For use in ground explosions, smaller mesh sizes are recommended to decrease fire and safety hazards. The wise pyro avoids the use of titanium in ground salutes and firecrackers because the hot metal sparks are hazardous.

Water [H₂O]—Water has many uses in pyrotechnics. When using it as a solvent or mixing aid, the experienced pyrotechnist prefers the purest water possible for most applications. Distilled water is probably the best, followed by deionized water. Tap water and well water are often not suitable for many pyrotechnic applications because of high contents of dissolved minerals.

Chinese Firecrackers



The Chinese firecracker is a wonder of ingenuity. With the most primitive of technology, the Chinese have produced this product in one form or another for hundreds of years, and in astounding quantities, given the lack of automation in the process. Traditionally, the manufacture of firecrackers was a small cottage industry. The manufacturers produced their own paper for the cases and wrappers, although they often bought paper for fuses from the Japanese. The black powder used was made under similarly low-tech conditions.

TRADITIONAL TECHNIQUES

The modern pyrotechnist has several options for making a product that nearly duplicates the traditional Chinese firecracker. First he must decide whether to go as far as to make his own paper for cases. It is certainly simpler to use plain, brown kraft paper than to make the paper. However, the Chinese used a recycled fiber paper as a rule that often included newspapers, old books, packaging paper, and even toilet paper. In the old days punk powder (incense) or other fragrances were sometimes added to the paper to impart a pleasant scent. This perfumed scent is conspicuously absent from modern firecrackers. The artist may want to go as far as making his own paper if authenticity is a major consideration.

The concept is simple, although the process is rather involved. Fiber for the paper can come from any other wastepaper, or natural fiber cloth, or shredded plant fiber from plants like hemp. The fiber needs to be cleaned and suspended in a water bath along with any fragrance, color, or binding agents. It is filtered out on screens, then stacked, pressed, and dried. Then the paper is cut to size for tube rolling. There are many fine books available on the art and craft of paper making.

Chinese Firecrackers is an excellent film that shows traditional Chinese firecracker making in Shanghai around 1948. This film has been widely duplicated and circulated among the members of the Pyrotechnics Guild. *Chinese Firecrackers* has also been available as a 16mm film from the University of Illinois Film Library. The film shows the manufacture of the old "double voice" crackers, including making the tubes using a "pulling bench" and a cylindrical case former. The pulling bench is essentially a table, above which is suspended a weighted board that is free to move back and forth like a pendulum just above the table's surface. Paper sheets with some glue are rolled around a cylindrical wooden case former and then rolled under pressure on the pulling bench to the desired size. The cases are then cut to the desired size with a sharp knife, while still wet. The trimmed tubes are hung up in open air and allowed to dry.

Making Tubes

Making hand-rolled cases without even a "pulling bench" is perfectly feasible in small to moderate quantities. All that is required is a clean, flat work surface, a cylindrical case former such as a lacquered wooden dowel or brass rod of appropriate diameter (that is, matching the inside diameter of the finished tube), some glue or paste, and a quantity of rectangular cut sheets of paper. Firecracker cases are "dry-rolled," meaning that the adhesive is applied only to the very inside and outside layers of paper. This is done so that when the cracker goes off, it shreds into confetti rather than exploding into large chunks of woodlike cardboard, which would happen if the case were "wet-rolled" with paste or glue applied throughout.

The procedure is described in George Weingart's *Pyrotechnics*

and other books. The paper is fanned out on the rolling surface so that a strip of glue can be applied to both the leading and trailing edge of the paper stack. A good glue to use is a wheat paste, such as wallpaper paste, with about 5- to 10-percent sodium silicate solution added to the finished paste to harden the tubes. The case former is then placed on the leading edge of the paper stack. The sheet(s) of paper required are folded over the surface of the former, which is then rolled up the surface of the rolling table. When the paper tube reaches the end of the sheet, the glue on the sheet seals the outside of the tube. The case former is removed and the tube stacked vertically to dry. A band saw or tubing cutter can later be used to cut tubes to desired length. Some pyrotechnists use a tubing cutter designed to cut plastic pipe for plumbing purposes. This cutter resembles a pair of pliers with a razor-sharp blade on one face.

Another good way to make tubes is to use adhesive-backed kraft paper tape rather than plain kraft paper; it is easy to use for small-diameter tubes. The paper tape is simply rolled on the former, wetting the inside edge, and wetting the outside edge. The rolled tube is then tapped on the tabletop to straighten out the top and bottom of the tube before the glue sets firmly. This process can be modified to produce a top-notch wet-rolled case for whistles, rocket motors, German-style Knallkörpers, or British-style thunder flashes. Supplies used include several case formers made of solid brass or aluminum rod, some petroleum jelly, some transparent plastic tape, cut pieces of kraft paper tape, and a tray of warm water. All but one of the metal rods are lightly greased with petroleum jelly. Next, a piece of paper tape is rolled around the rod tightly, forming a dry tube. The pyrotechnist then taps the end of the tube on the table so that it becomes nice and even. The outer edge of this tube is fastened shut with a piece of transparent plastic tape along its length, but leaving some paper exposed. The maker then slides this tube off onto one of the greased rods. The process is repeated until he has as many tubes as his rods will accommodate. Then he places them all in the tray of water and allows them to soak several hours. Finally, the tubes are removed from the tray and allowed to dry thoroughly while still on the forming rods. The plastic tape is removed from the

tubes, which will then slide easily off the rods. If the procedure has been followed correctly, the artist should now have some excellent quality parallel-wound tubes.

Of course, commercially made tubes are usable, if not as authentic. Several suppliers sell commercially made tubes for pyrotechnics. However, many hobbyists and professional pyrotechnicians alike get and use tubes made for other purposes. Window shades, for example, are often rolled on paper tubes. Other tubes are used to package drill bits and other tools. Mailing tubes, still made of paper, work well for firecrackers and also for mortar tubes suitable for aerial salutes. The pyrotechnician is an inveterate recycler who looks at the world with eyes ever attuned to the possibilities present in cast-off junk.

Making Black Powder

The most basic powder is what we know as black powder, the original variety of gun powder. Now it is still possible to buy and use commercial black powder such as is used for antique cap-and-ball pistols and rifles. Yet, to use this commercial powder can take much of the enjoyment out of making fireworks. There are several variations on homemade black powder. One good method is described in *CIA Improvised Black Powder*, published by Desert Press and available from many booksellers who cater to the paramilitary crowd.

In a nutshell, the method involves using a kitchen blender to mix a slurry comprised of 75 percent potassium nitrate, 15 percent air float charcoal, and 10 percent sulfur (percentages by mass) in hot, distilled water. The amount of water used should be sufficient to yield a mixture that has the consistency of a thick milkshake. The mixture should be as close to boiling as possible when the mixing starts. The composition is mixed in a blender for several minutes (longer if the charcoal is coarser than air float). Then the pyrotechnician adds a quantity of alcohol—denatured ethyl alcohol, pure isopropyl alcohol, or pure methanol (e.g., gas line antifreeze)—equal in weight to the water used. An immediate decrease in the speed of the blender is noticeable. This is because the potassium nitrate, which is very soluble in hot water, is nearly insoluble in a 50/50 mixture of water and alcohol. When the alcohol is added to the water/nitrate

solution, the potassium nitrate precipitates (drops out of solution) quickly, forming minute crystals throughout the suspended charcoal and sulfur mixture. The blender runs for several more minutes; this keeps the crystals of nitrate very small. The slurry is then run through filter paper in a filtration funnel. Some hobbyists substitute for a filtration funnel the coffee basket and filter from a drip coffee maker. The leftover water/alcohol mixture is discarded. The remaining semisolid mass of slurry can be spread out on paper, such as several old newspapers, to dry in the sun. When the mass is nearly dry and crumbly, it is run through a coarse brass screen to break it up into a coarse powder. When completely dry, this powder can either be crushed with a rolling pin to make fine powder (meal) or used in larger, popcorn-sized chunks in larger crackers or to lift aerial bombs from mortar tubes.

There are several variations on this method, most of which work quite well. In all cases the wise pyrotechnician uses great care and treats the powder with the respect it is due.

Paper Firecracker Fuse

The paper fuse found on most Chinese firecrackers is made from a paper whose origin, either in style or in fact, is Japanese. It is very long-fiber tissue paper, either Ganpi (Gampi) or some other variety. If the artist wishes to make his own he will need a good grade of Japanese tissue paper. The Western varieties of machine-made paper have shorter fibers and are not strong enough to do the job. Many of the natural papers used to cover the frames of model airplanes are quite suitable and affordable. More expensive, although often better in quality, are the high-quality Japanese tissue paper used by artists. Larger art supply stores often carry these. When the wise pyrotechnician finds a good source for a suitable paper at reasonable cost, he buys it and saves it because it is not always easy to find. These papers are made by hand in small quantities, and availability varies from month to month and year to year. Also, the model airplane hobbyists have lately been turning more and more to synthetic coverings for their work. This trend may reduce availability of the ordinary Japanese tissue that is so suitable for making paper fuse.

In addition to Japanese tissue cut along the grain into strips about an inch wide and perhaps a foot to two feet long, the fuse maker should have a good grade of homemade meal (fine dust black powder), a dish of water to which has been added some potassium nitrate (about 5 to 10 percent), and a dash of dextrine (about 1 to 2 percent). A clamp to hold taut the end of the fuse paper will be useful—a mounted wooden spring clothespin will work nicely. A traditional powder dispenser can be made from a joint of bamboo with a small hole drilled in one end and a cork closing the open end of the tube.

The paper strip should be creased lengthwise down the center. Then the fuse maker clamps the end of the paper strip so that he can hold the other end with the left hand, forming a trough of paper. With the right hand, he sprinkles the meal powder from the dispenser into the open trough as evenly as possible. Then he evens out the powder train with a finger. Next, he grasps the paper trough with the left hand and begins to twist tightly the very end of the paper strip so that it forms a spiral wound tube filled with black powder. Keeping the paper taught, he releases the paper from right hand's grasp while twisting quickly with the left thumb and index finger. Finally, he dips his right thumb and index finger into the water/potassium nitrate mixture, gently and slightly dampening the fuse along its entire length while applying a slight crease lengthwise. He removes the fuse from the clamp and allows it to dry. When the fuse is completely dry, it is cut into finished lengths with a razor blade or very sharp knife. Appropriate lengths are about half again as long to twice as long as the cracker the hobbyist wishes to make. Practice, practice, practice is required for competence. After some time doing this, the hobbyist will come to a greater appreciation of the art of making small firecrackers.

Making Firecrackers, Chinese Style

Chinese crackers are generally made in large hexagonal bundles of 1,000 or so tubes. The cut tubes are stacked in a former and tied together, and then all of the bottom ends are crimped shut with a sharp bamboo stick. The bundle is flipped over and covered with a

glued sheet of paper that seals all the tubes. Another sheet of paper is wound around the side of the bundle, forming a boxlike, hexagonal tray atop the tubes. A sharp stick is used to puncture the tops of the tubes. The required amount of powder is then poured into the tray. The bundle is shaken horizontally until all of the tubes are filled. A little powder is emptied from each tube with a knock of the palm on the diagonally held bundle. Fuse is inserted in each hole. Finally the fuse ends are crimped shut similarly to the bottoms of the tubes. The crackers are then ready for braiding and packaging.

It is more practical for the Western hobbyist to make quantities smaller than a thousand. Yet the same basic technique has an advantage over making the crackers singly: the time required to produce the firecrackers is reduced, so more can be made with a similar amount of work. Making them a little larger makes for a more impressive device that is also easier to handle with clumsy Western hands. Some hobbyists roll their tubes on a $\frac{1}{4}$ -inch former, making them about $\frac{3}{8}$ inch to $\frac{5}{8}$ inch outside diameter. The specifications for the tubes are variable. However, the tubes in each separate batch need to be uniform in size or else the bundle will be unmanageable.

The pyrotechnist makes a uniform hexagon of the finished tubes about 4 inches on each side and ties this bundle top and bottom with strong string—flax twine that shoe makers use works well. Then he seals the bottoms with crimps, using an ice pick or scratch awl. Turning the bundle over, he seals the tops with a sheet of thin, pasted, kraft paper. A strip of pasted kraft goes around the "circumference" of the bundle, forming a shallow tray on top. Then the artist allows the paper to dry.

To load, the pyrotechnist starts with a small amount of clay if making a black powder cracker. Ordinary red, powdered clay from a ceramics supply house works well. This is tamped into the bottom of the tubes with a brass rod. Next he pours in the meal powder to fill the tubes, knocking a little out afterward. (Good quality commercial meal makes the best cracker, but good quality homemade meal is probably closer to the historically authentic mixture used by the Chinese for centuries.) Then he places the fuses down into the pow-

der of each cracker and tamps them gently into place with the brass rod. Then he adds another measure of the powdered clay and tamps that into place. The pyrotechnist cuts the string on the bundle and then finishes each cracker by tying a small piece of strong thread around the fuse end of the cracker, choking just enough to hold the clay in.

To make flash crackers, he follows the same procedure but omits the clay and the final string tying entirely, merely crimping both ends shut with an awl. Flash should never be tamped, either; in fact, it works best when left loose in the tube. See the chapter on flash powder (Chapter 5) for procedures on making and handling flash.

Ordinary glassine paper from an artists' supply shop can be dyed any color imaginable and makes a great cracker pack nearly indistinguishable from the old fashioned Chinese cracker packs. A modern personal computer coupled with a color ink jet printer can produce amazing labels, and even wrappers for individual crackers. The artist is limited only by his imagination.

Flash Powder



Flash powder, the silvery or gray powder used in flash firecrackers, silver salutes, M-80s, and the like, is easier to make than black powder, but more dangerous. There are myriad variants of flash powder, but all use a metal powder as fuel, combined with an oxidizer or oxidizers such as potassium perchlorate [$KClO_4$] or potassium chlorate [$KClO_3$], and sometimes with another fuel component or components that act to modify the burning rate (such as antimony sulfide), or to desensitize the mixture (for example, stearin). Several formulae are given here, all of which can be used. A rule of thumb is that the hotter the mixture, the more successfully it can be used in smaller devices. The larger the device, the less one has to be concerned about the particle size of the fuels or oxidizers, or how well-mixed is the composition. For small firecrackers, that is, smaller than a cherry bomb, these considerations are more critical. The compositions below are ranked in order of increasing potency and increasing sensitivity to accidental ignition. The first two mixtures are the least dangerous to make and use.

FLASH COMPOSITIONS

Some flash formulae are as follows:	(percentages by mass)				
	1	2	3	4	5
Potassium perchlorate [KClO ₄]	70	70	66	64	29
Potassium chlorate [KClO ₃]					27
Aluminum powder, German black [Al]	30	15		27	22
Aluminum powder, American dark [Al]		15	17		
Antimony sulfide [Sb ₂ S ₃]			9	15	
Sulfur [S]		17		7	

Some pyrotechnists say to religiously avoid mixtures containing chlorates and sulfur or sulfides. Such mixtures are invariably more sensitive than simple mixtures of oxidizer and metal powder. Also, the wise pyrotechnist who chooses to use sulfur is always certain to use a good grade of sulfur without acid content, since the presence of acids in such mixtures can trigger spontaneous combustion. Sulfur can be mixed with an alkaline buffer such as magnesium carbonate to help avoid this problem. Less than 1 percent of buffer is generally sufficient for this purpose.

There is a price to be paid for using most of the hotter flash mixtures. Most of these compositions use one or more accelerants added

to the basic fuel/oxidizer mixtures (e.g., sulfur or antimony sulfide). One pyrotechnist friend, a dedicated fan of exploding fireworks, uses only plain 70/30 potassium perchlorate/American dark aluminum flash mix. He once observed that when he wants a louder bang, he simply makes a bigger salute. He believes that adding accelerants such as sulfur and antimony sulfide increases the risk of handling flash with little or no added benefit. Therefore, for the overwhelming majority of applications in exploding fireworks, ordinary 70/30 or 2:1 potassium perchlorate/aluminum flash mix is best.

Regarding the different grades of aluminum powders, there are substantial differences in how well they work for flash mixtures. The best for small firecrackers are those with small particles of flake shape. Granulated powders work less well, and atomized (rounded) powders work poorly. The best grades are the German black and the American dark types. Some pyrotechnists shy away from the German black because they believe it is too reactive for their own safety. German black is, however, without parallel in terms of the quality of report it produces in small- to medium-sized firecrackers. The Chinese tend to use a grade of aluminum similar to what we Western pyrotechnists call a -325 mesh "bright" aluminum in most of their exploding fireworks with very good results.

If aluminum powder of pyro grade is unavailable, one should not substitute magnesium, zinc, or other powdered metals. It is possible, practical, and safer to make a good grade of aluminum powder starting with either aluminum foil chunks or coarse flake aluminum ("flitters"), which can be ball milled in an ordinary rock tumbler with a grinding medium such as steel ball or roller bearings. The wise pyrotechnist is always careful with this process to include some surfactant such as stearin or Ivory soap in a small percentage, lest the process turn out a pyrophoric powder that will ignite on contact with atmospheric oxygen.

Now, a few more words about safety. Flash powder, as any other high-energy mixture, requires special care in manufacture and handling. It is sensitive to heat, friction, shock, and static electricity. Flash will explode in small quantities when confined minimally. In larger quantities, past a "critical mass," flash will explode even when

unconfined; for example, a large enough pile of flash can explode while lying uncovered on a sheet of paper in the work area. For ordinary 70/30 flash with no additives, the critical mass at which unconfined detonation is likely to occur is around 50 grams. With the addition of additives such as sulfur or antimony sulfide, the critical mass is even smaller. The critical mass for chlorate-based report compositions is invariably tiny. Flash should be mixed outdoors on a day with relatively high humidity, as this tends to minimize static electricity buildup. The maker should wear face protection and a good respirator to prevent inhalation of the aluminum powder, which is injurious to the lungs. The wise pyrotechnist is extremely wary of the tendency aluminum dusts have to float in the air around the work area. Aluminum dust clouds are explosion hazards, especially in the presence of flame or sparks. Mixing is always done by hand—never with electrical tools or appliances. One should never grind flash in a mortar and pestle or in anything else.

One pyrotechnist mixes flash as follows. He prepares his potassium perchlorate by first running it through a 40 mesh sieve. Then he adds $\frac{1}{2}$ percent Cab-O-Sil (fumed silica dust) to keep it fluffy and runs it through the sieve onto a cut sheet of kraft paper. He places the weighed out aluminum powder (and any other components other than the perchlorate, chlorate, or nitrate) on another sheet of kraft paper. He adds to this fuel the freshly sifted perchlorate (or chlorate or nitrate, or other oxidizer) and begins the mixing process by lifting the corners of the paper in rotation, pulling the edge of the pile of powder over on itself again and again. When the mixture appears homogenous, he then carefully sifts the mixture twice through a 30 mesh brass sieve. Under no circumstances does he use any tool other than his finger or a soft, clean, natural hair paint brush to get the powder through the sieve. He makes up only as much powder as he will use at the time, since storing loose flash is extremely hazardous.

One knowledgeable pyrotechnist recommends that anyone contemplating mixing photoflash mixture of any kind consult with an experienced pyrotechnist before experimenting. A good source of information is the seminar on flash powder given annually at the

convention of the Pyrotechnics Guild International. Another would be a manufacturer of display fireworks, of which there are dozens around the country. A little knowledge is a dangerous thing.

The American Cannon Cracker



Originally the term "cannon cracker" was applied to the larger Chinese black-powder firecrackers that became popular in the United States in the years following the Civil War. Toward the latter part of the 19th century, the Chinese firecracker had a virtual monopoly on the American recreational explosives market. The American fireworks industry responded with an American version of the cannon cracker. Until well into the 20th century, firms such as Masten & Wells made and marketed large, usually powerful firecrackers that were known popularly as cannon crackers. These firecrackers came in many sizes, from smaller ones the size of a modern M-80 up to gigantic salutes more than a foot long and well over an inch in diameter. These cannon crackers used a variety of explosive compositions, most often based on potassium chlorate and sulfur or antimony sulfide and charcoal. Some manufacturers even used nitroglycerine, dynamite, or other true high explosives in their formulations. So even though often comparable in size to the older Chinese cannon crackers, the American cannon crackers generally had much more explosive power than a Chinese firecracker, although less power than a flash salute of similar size. Most often, these cannon crackers were fused out one end with a piece of blasting fuse and sealed with a plug made of paper, clay, or cork on the other end. As the newer metal-based flash and sound

compositions became popular during the 1920s, cannon crackers declined in popularity.

MAKING CANNON CRACKERS

The cannon cracker requires a rather large tube. Many prefer a good, heavy, spiral wound tube for this application, since the parallel-wound tubes tend to fragment when exploding. A bright red tube lends the old-fashioned cannon cracker look. For fuse, lengths of Japanese time fuse or American-made blasting fuse lend the look of authenticity to the finished crackers. However, the user needs to be aware that these time fuses do not burn away as do ordinary safety fuses, and special care is in order. The fact that users were often unable to tell when a fuse was lit was one of the major problems with these firecrackers even in days of old. Use of more modern visco safety fuse can remedy this problem. Although the old cannon crackers often had crimped closures, modern pyrotechnists can use commercially made kraft paper end plugs or more historically authentic old-fashioned natural corks glued in place with hide glue to seal the tube ends.

The artist begins by gluing the bottom plugs in the cases. Next, he prepares a sufficient number of lengths of fuse for fusing the crackers. These are usually half the length of the tube plus two inches long, and cut diagonally to expose a greater area of powder core. He finishes the fuses by coating the ends with nitrocellulose/black powder prime to ease ignition and seal the powder core in the fuses. He mounts the fuses in the second end plugs by punching a hole in the plugs with a paper or leather punch and then glues the fuses in place with hide glue. When the end plugs are dry, the pyrotechnist fits the tubes upright in a jig that holds them in place for filling and fusing. This jig is simply a board with holes drilled into the top surface with a drill press. These holes are just barely larger than the outside diameter of the tubes.

Then he mixes the cracker composition. Since cannon cracker compositions are chlorate-based mixtures, special care must be taken in both mixing and loading the powders. The wise pyrotech-

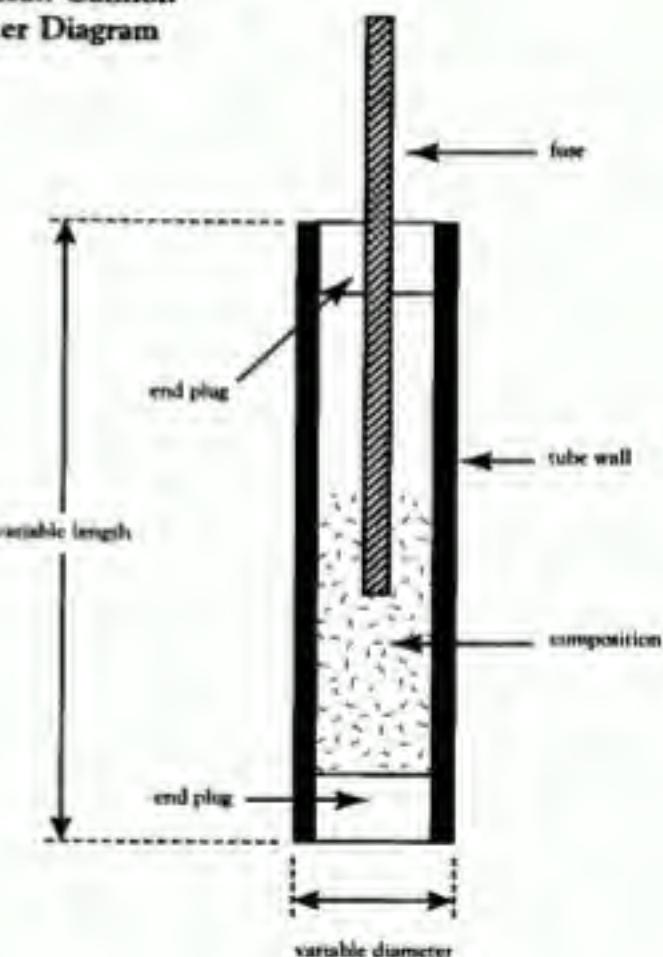
nist remembers that chlorate-based compositions are invariably more sensitive to friction, shock, and other stimuli than are nitrate- or perchlorate-based mixtures. The wise pyro never sieves chlorate-based mixtures. He mixes them by hand on a sheet of acid-free paper or uses a natural bristle artist's paint brush as a stirring tool. The best kind of brush for this purpose is a soft Japanese artist's brush that is made from bamboo and long, fine horse hair with no metal ferrule that would be likely to produce a spark. Probably a safer method is to mix these compositions wet and then granulate through a coarse sieve while still damp. The tubes can then be loaded when the composition is dry or nearly dry.

Cannon Cracker Compositions

Some formulae are as follows:	(percentages by mass)			
	1	2	3	4
Potassium chlorate [KCIO ₃]	57%		57%	50%
Potassium perchlorate [KCIO ₄]		40%		
Antimony sulfide [Sb ₂ S ₃]	29%	20%	29%	
Charcoal, AF				25%
Sulfur [S]	14%	20%	20%	
Rosin				14%
Red Gum (Accroides)				25%

Next, the pyrotechnist uses a powder scoop to fill the tubes one-third to one-half full of cannon cracker composition. This process requires great care, since most of the cannon cracker compositions are very sensitive to heat, impact, and friction. These compositions demand gentle treatment! Finally, he glues in the top plug-and-fuse assemblies with hide glue, gently sliding them into place. The glue is allowed to dry, and the old-fashioned cannon crackers are ready to go!

American Cannon
Cracker Diagram



Hitt's Flashcracka



Decades before the M-80 was dreamed up by the U.S. military, an American fireworks manufacturer named Hitt invented a nifty firecracker he called the "Flashcracka." The name Flashcracka was a trademark adopted because the term flash cracker had already passed into common usage and was not considered eligible for trademark status. This was one of the early flash salutes; some say the earliest, but this is probably not so. A man named Karl Gelingsheim, a German, described the uses of photoflash mixes in fireworks in 1913. We do know that Thomas Hitt applied for a U.S. patent on such a firecracker on August 2, 1917, and was granted patent number 1,253,596 on January 15, 1918.

Hitt's Flashcracka was essentially a small paper bag full of flash with a fuse running out of the top, tied with cord, and placed inside a larger paper tube long enough to have open air space at both ends of the tube. Hitt's Flashcrackas were fused with paper fuses as are the Chinese firecrackers, although Hitt's were often doubled or looped to avoid fuse failure. Hitt Fireworks advertised its firecrackers as "The cracker with the fool-proof fuse," a statement perhaps a bit too optimistic. However, in the days before product liability became an overwhelming concern among American manufacturers (recall the days when there were American manufacturers of consumer fireworks), companies were not called to account for such exaggerations.

The modern pyrotechnist can make a similar cracker that functions in the same way. There are certain advantages of flashcrackers over ordinary firecrackers or salutes. First, they require no end plugs. Therefore, the maker can use any old cast-off paper tubes to make them and doesn't need to have exactly matched end caps or mess around with silicate adhesives or hot-melt glue. Also, flashcrackers are a great way to recycle old kraft paper shopping or lunch bags and odd bits of string. Finally, it has been observed that flashcrackers have an unusually sharp report.

Requisite for making the flashcracker are some paper tubes of appropriate size. About $\frac{1}{4}$ inch inside diameter and 4 inches in length is good, but any size from about $\frac{1}{8}$ inch up to 1 inch inside diameter and from 2 inches up to 8 or more inches long will do. The best proportion of outside diameter to length seems to be about 1:5. Also needed is a dowel about $\frac{1}{8}$ inch smaller in diameter than the inside diameter of the tubes and some lightweight kraft paper strips equal in width to the length of the tubes and about 10 times the tube diameter in length. For fuse, the pyrotechnist can use American-made visco safety fuse, cut about one-third longer than the tube. A helpful jig to hold the tubes upright while filling can be made of a wooden board into which several holes are drilled slightly larger than outside diameter of the tubes to be filled.

Ordinary 70:30 potassium perchlorate/aluminum flash powder can work well as a composition for the flashcracker. For an air of historical authenticity, the traditionally inclined pyrotechnist may want to use the following original mixture that Mr. Hitt patented back in 1918. Hitt's original mixture is heavy on the aluminum compared to most flash mixtures and so produces a very bright flash as well as a good report when the remaining metal powder burns in the open air just after the explosion.

Hitt's Flash Powder

(percentages by mass)

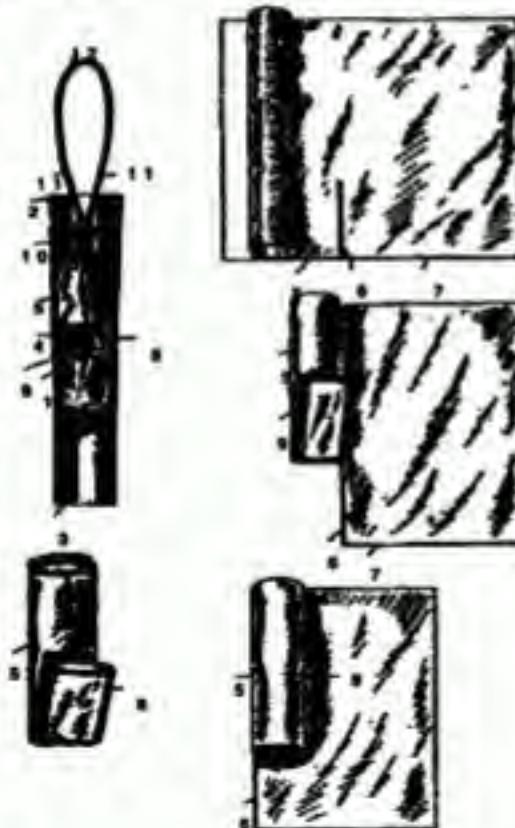
Potassium perchlorate [KClO ₄]	49%
Aluminum [Al]	42%
Sulfur [S]	9%

The pyrotechnist begins by taking a piece of the cut kraft paper and winding it around the end of the dowel, forming an open tube. He then slides the paper tube partially off the dowel, about 1 inch for a $\frac{1}{8}$ -inch inside diameter cracker. Then he folds the paper so that the end of the kraft tube is sealed, with the paper folding over the end of the dowel and a little up the opposite side. He then places the dowel and sealed tube end into the larger paper tube and stands the tube upright. Then he withdraws the dowel, leaving an empty paper cylinder protruding about an inch out of the top of the tube. The artist then places a scoop of flash powder inside the tube and follows up with a cut piece of safety fuse. Then he uses a piece of string to tie off the top of the inside tube with a clove hitch. With practice a clove hitch can be tied very quickly with just one free hand. Then he dabs a bit of glue in the inside of the bottom of the tube and slides the flash bag down to the middle of the tube. Now he has a near facsimile of the old-fashioned Hitt's Flashcracka that's sure to be a "Hitt" with the neighbors.

T.G. Hitt Flashcracka Diagram

The Hitt Flashcracka consists of a paper tube containing an inner paper flash bag. This bag is made of a thin kraft paper rolled into a tube as shown. When partially inserted into the outer tube, the bag is filled with flash mix, a fuse is added, and the bag is tied shut. The bag is then pushed into the center of the outer tube and glued in place.

1. Paper body tube
2. Opening in top of body tube
3. Opening in bottom of tube
4. Flash powder
5. Paper flash bag
6. Cut made in paper for forming closure flaps of flash bag
7. Outer wrap of paper for flash bag
8. Outer bottom flap of paper flash bag
9. Inner paper flap closure of flash bag
10. Neck of flash bag tied off with string
11. Safety fuse
12. Loop of safety fuse (assures ignition of two fuses for decreased risk of ignition failure)



The Cherry Bomb



The so-called cherry bomb is another early 20th century salute. The details of its origin are obscure, but patent records show that U.S. patent #1,783,999 was granted to Alberto Cimorosi of Elkton, Maryland, in December 1930. The salute pictured in this patent was originally called the Globe Flash Salute and later the cherry salute or cherry bomb in the vernacular. These salutes were more or less spherical in shape, usually red, and fused with a thick green safety fuse. They resembled a cherry in size, shape, and color. Later the term "cherry bomb" became bastardized among the general public to mean any large firecracker; this less specific use of the term is not, however, strictly correct.

Originally, the cherry bomb was made by filling two die-stamped paper hemispheres with flash, then tumbling the filled case in a "sweetie barrel"—a tumbler originally designed for making spherical candies—with alternating layers of adhesive and sawdust. After the final layer dried completely, the shell was drilled through and a piece of safety fuse inserted in place.

For the contemporary experimenter there are at least a couple of ways to proceed practically. Both use the commercially prepared "cup sets" that are available from suppliers of pyrotechnic paper goods. Should these become unavailable, it would be relatively simple to create a simple die

and stamp setup that could produce such cup sets in a small workshop setting.

Sawdust from a table saw can be sifted into grades of different particle size as needed for this process. For both methods, some colored sawdust will be needed for the final coating. This can be made by treating some fine sawdust with red dye or with tempera paint and allowing this to dry. Drying the sawdust can be a slow process, taking several days prior to beginning the rest of the project.

One method that is not historically authentic but quite serviceable is the "dip and roll." For this the pyrotechnist uses a jig that holds the bottom cup of each set snugly but which leaves free the top half-inch or so of the cups. He places the cups in the jig and fills each half full with flash. He punches the top halves of the cup sets with $\frac{1}{8}$ -inch holes through the centers. Then he inserts a two-inch piece of green safety fuse and glues the fuse in place with the rounded side of the cup upright on the work table, pushing the fuse through to the table surface. This positions the fuse ideally in the finished firecracker. Next, the pyrotechnist paints the exposed outside rims of the inner cups in the jig with white glue. Then he carefully slips the top cup over the bottom one and allows the glue to set for a few minutes before removing the salutes from the jig. He removes the cup sets and allows them to dry thoroughly before proceeding to the next step. If the glue doesn't dry well, the cups can come apart in the next stage of the process. When the first glue has dried thoroughly, he dips the cups in Elmer's once more and then immediately rolls the glue-covered cracker in sawdust. A coarse (20-30 mesh) sawdust is best for the first "roll." Now the cherries are dried in the sun or in a warm, dry place overnight. The following day he dips the cherries once more in glue and rolls them in a finer sawdust, such as a 40-50 mesh powder. The next day he repeats the process but uses a sawdust that has been dyed red for the purpose and allows this to dry thoroughly.

An alternate and more historically authentic method is to fill the cup sets with flash and glue as above but leave the top half undrilled. The pyrotechnist then coats the spheres when dry with a hide glue, such as Franklin's Hide Glue or LePage's Glue. Excess

glue is drained off through a strainer. When the glued surface of the cups becomes quite tacky, the artist rolls them in 20-30 mesh sawdust and allows the devices to dry thoroughly. Then he coats the salutes with sodium silicate solution (sold as "water glass" or "egg preserver"), allows them to drain, and rolls them in the finer sawdust. The salutes are allowed to dry thoroughly. Then the pyrotechnist repeats the silicate coating and roll in the red-dyed sawdust. He allows this to dry thoroughly until the cherries are quite hard. This may take several days, depending on the humidity, whether the devices are dried in the sun or shade, and so forth. In the old days, such salutes were often dried with steam-heated forced air. Some modern pyrotechnic hobbyists have used commercially available vegetable dehydrators for drying various fireworks with good results.

The most dangerous part of the operation is drilling the cherry salutes for fusing. This is one stage of the operation when leather gloves and good eye and ear protection are musts. When the cherries are dry, the pyrotechnist uses an electrically grounded drill press or even a simple hand drill (X-Acro makes a good one) with a sharp, waxed drill bit to drill carefully, only just into the hollow inner cavity. It is handy to either lay in a large supply of fresh drill bits or have a bit sharpener available for use. He sets the drill press so as not to drill into the opposite side of the cherry bomb, since this would create a greater friction hazard. If he is using a hand drill, a drill stop can be used for the purpose. Then he inserts a 2-inch piece of green safety fuse into the hole and glues it in place. A small dab of hide glue will cement the fuse in place. These finished salutes should be dried quickly, lest the water content of the glue damage the fuses. The wise pyrotechnist removes finished salutes from the drilling area immediately after drilling to minimize risks of accidental explosions during this process.

The pyrotechnist can use either an ordinary flash composition for the explosive charge or use the following mix, which is a flash composition used by the Kent Fireworks Co. in its cherry bombs during the 1960s.

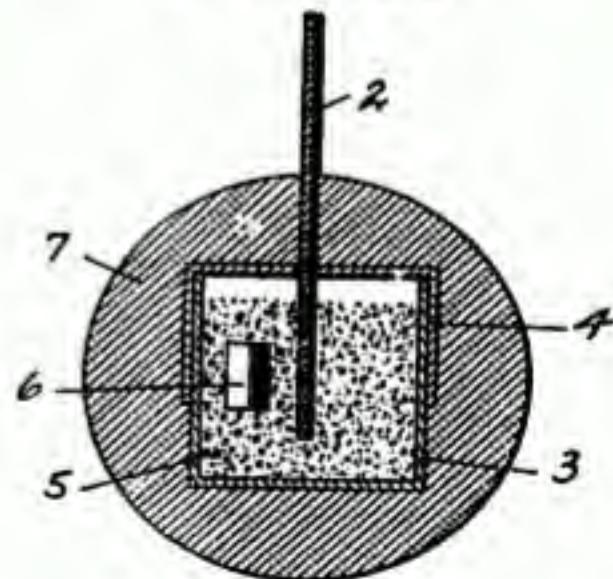
Kent Cherry Bomb Composition

(percentages by mass)

Potassium perchlorate [KClO ₄]	50%
Sulfur [S]	7.5%
Antimony trisulfide [Sb ₂ S ₃]	17.5%
German black aluminum [Al]	25%
Manganese dioxide [MnO ₂]	+0.5%

Cherry Bomb Diagram

1. Agglomerated shell
2. Fuse
3. Inner cup
4. Outer cup
5. Explosive composition
6. Colored star (optional)
7. Agglomerated shell

FIG - 1 -FIG - 2 -

Ash Cans



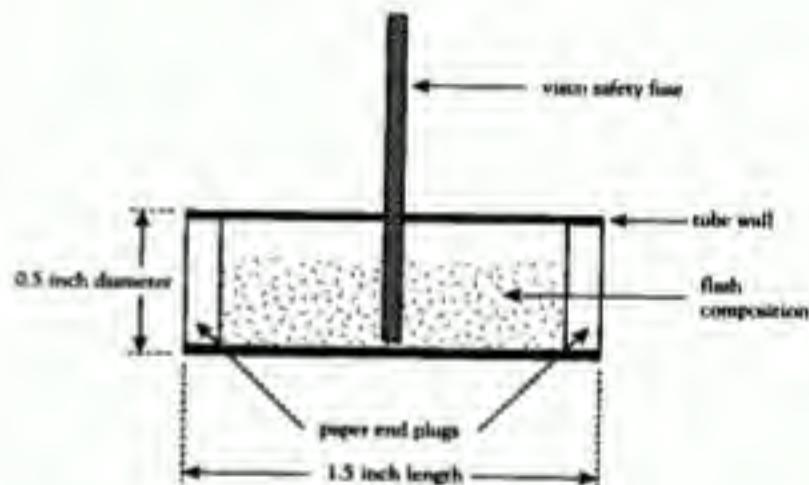
Ash cans, bull dogs, hammer-heads, silver salutes, silver tube salutes, side-fuse tube salutes—the names changed from one decade to another and from one maker to another, but the construction and function remain basically the same. These were American-made firecrackers made from small cylindrical tubes, filled with flash, plugged at both ends with either paper plugs or some sort of adhesive cement, and fused, usually out the side of the tube, with a heavy safety fuse. There were many variations, but the ones I recall best were made in the late 1960s by Miller Fireworks of Holland, Ohio, and by United Fireworks of Loveland, Ohio. These particular items were $1\frac{1}{2}$ inch long, $\frac{1}{8}$ inch inside diameter, made from a silver colored spiral wound tube. Around the outside of the tube was printed the ominous legend "DO NOT HOLD IN HAND" in small capital letters printed in a continuous spiral so that each tube was covered with probably a dozen or two complete and partial warnings. The ends of the tubes were plugged with glued-in paper end caps. The fuses were of excellent quality and were set in the tubes with a small dab of glue so that the salutes never leaked powder. Careful dissection of a live specimen revealed that it was filled about half full with a dark-colored flash powder. Years later, examination under the microscope revealed a flash powder composed of potassium perchlorate and dark aluminum.

A few years later I came across some bootleg ash cans that were rather poorly made. The salutes were the same size, but all the silver tubes lacked the traditional "DO NOT HOLD IN HAND" warning. The ends of the tubes were plugged with silicate cement, which was often cracked and leaking flash powder into the bag. These were more dangerous than the older ones, but at the time I did not truly appreciate just how much more dangerous. When the law banned these devices, consistent quality control became a thing of the past.

In any case, it is now impossible to buy those neat old silver tubes with the distinctive printing on the outside. But others can be had, either from pyrotechnic suppliers or from other sources. Or homemade tubes can be made and finished with glued-on tinfoil or silver-colored origami paper. The pyrotechnic hobbyist is limited only by imagination.

The basic concept is very simple. The pyrotechnist simply takes his tube, plugs one end with a paper cap of appropriate size, and glues that in place with white glue. Next, with an awl he drills or punches a hole for the fuse in the center of the tube. A drill press with an appropriately sized drill bit will give a more consistently sized fuse hole than an awl, as a rule. Remember, the wise pyro drills and fuses these salutes before loading with composition. Then he places a 1 1/8-inch length of visco safety fuse through the hole and glues it in place. The best kinds of glue for this are probably low temperature hot melt (provided one is working outdoors and away from other flammable materials) or a small dab of hide glue. The pyrotechnist wants to avoid the chance of moisture from a water-based glue affecting the powder train inside of the fuse. Good visco safety fuse is water-resistant, but not always truly waterproof. He places the tubes, open end up, in a jig, and fills them half full of flash. He glues another cap in the open end of the tube. He allows the glue to dry, and . . . an old fashioned ash can is ready to go.

Ash Can Diagram



The M80



For some reason, M80s have ended up as the bad boys of the firecracker world. They are certainly no larger than many of the old firecrackers, but they have received a disproportionate amount of bad press over the years. Originally, the M80 was a military training device designed to simulate small arms fire in basic training. The "M80" designation was a military product identification code number. The U.S. government contracted with several fireworks makers to produce these hefty salutes. Military issue M80s are made from a plain, brown kraft paper tube 1 ½ inch long, and ¾-inch inside diameter, fitted with a stiff, green visco fuse and packaged in boxes of 50. Each box is hermetically sealed in foil-backed cloth packaging. Each salute bears the words "M80 Firecracker" and the date of manufacture "4-64." Careful dissection reveals that each firecracker is double plugged at each end with a paper disk and an end cap. The M80s are filled completely, with no air space, using a dark flash mixture. This differs from most flash salutes, which function optimally with some air space and loose powder. Perhaps this was done because of some government specification that had little to do with performance, or perhaps they knew something I don't. From a standpoint of design, these are odd firecrackers.

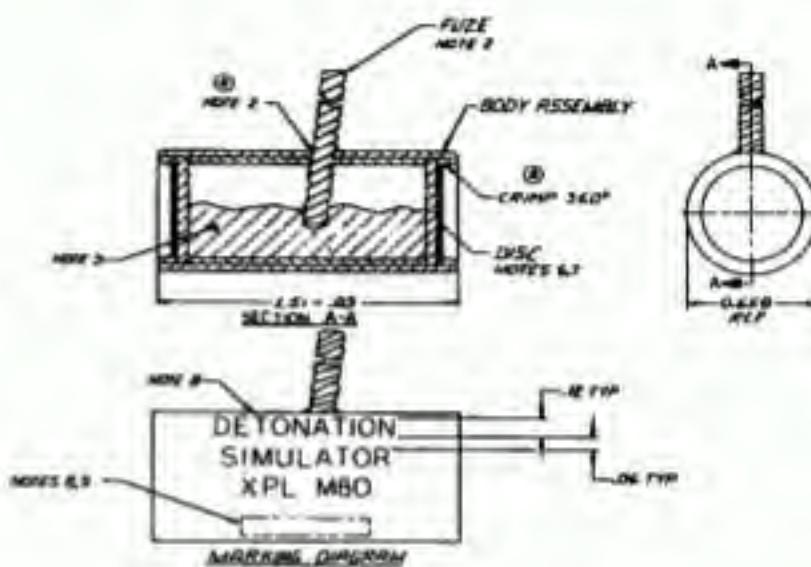
After World War II the M80 was marketed as a fireworks item for civilian use. The first ones on the

market were war surplus, the genuine articles.¹ When some of the fireworks dealers saw how well they were received by the public, they began making civilian copies. These copies were sold by the millions in the 1950s and 1960s. The usual civilian M80 had a red tube of the original dimensions, bearing the words "M80 FIRECRACKER DO NOT HOLD IN HAND" printed on the outside in bold letters.

The pyrotechnic hobbyist making an ersatz M80 follows the same procedure as described in Chapter 9 for ash cans, except he uses the larger $\frac{1}{4}$ -inch inside diameter tubes and corresponding plugs. One can use either ordinary flash, or one of the following three formulae for M80 powder² reputed to be government-specified compositions:

M80 Powder

	(percentages by mass)		
	1	2	3
Potassium perchlorate [KClO ₄]	64%	66%	66%
Aluminum [Al]	22.5%	17%	17%
Sulfur [S]	10%		8.5%
Antimony sulfide [Sb ₂ S ₃]	3.5%	17%	8.5%



M80 Diagram
(from the original U.S. Military drawings)

The original M-80 firecracker was a device designed and produced for the U.S. military. This salute was used in training maneuvers as a rifle fire simulator. The design shown here is derived from original specifications. This particular version uses an end disk that is crimped in place over an inner tube liner. However, the specimens the author has seen use only a single, heavy-walled tube with end disks cemented and held in place with a paper end plug rather than with crimping. The civilian versions of the M80, so popular in the 1960s, used only a paper end plug or even a simple machine-made cement plug.

ENDNOTES

1. Personal communication with the late John Miller, former proprietor of Miller Fireworks of Holland, Ohio.
2. Joseph H. McClain, Pyrotechnics. (Philadelphia: Franklin Institute Press, 1980) 122.

The Globe Torpedo



Torpedoes, that is, impact-actuated firecrackers, have been popular since at least the early 19th century. Globe torpedoes were popular in the United States during the early- to mid-20th century. Over the years they have been available in many varieties in the United States and elsewhere. Some of these varieties have included the globe torpedo, the silver (fulminate) torpedo, the cracker ball, and the Japanese torpedo. There has been some confusion about the term silver torpedo, since some of the globe torpedoes were silver colored and hence often popularly called silver torpedoes. The term silver torpedo, however, is properly reserved for torpedoes made from silver fulminate, which actually used silver in the manufacturing process.¹ All torpedo fireworks use some impact-sensitive mixture, most often a fulminate salt or a chlorate/fuel mixture, to produce a report when thrown or struck.

Originally a trademark name, the term "globe torpedo" was later used by many manufacturers to describe several distinct but similar devices. The origins of this device are obscure. The first torpedoes were made with silver fulminate, followed by those made with potassium chlorate and red phosphorus-based explosives. (Called "Armstrong's mixture," the latter is an extremely hazardous and sensitive mixture that has caused many, many deaths and injuries in the fireworks industry.) In the United States, the manufacture of torpedoes of the

fulminate type was originally a cottage industry dominated by German and German-American immigrant families.

Joseph Dekker (also cited using the names "Josef" and "Decker" in various literature) patented a device similar to the globe torpedo with an agglomerated finish in 1925.² Dekker's torpedo was probably the model for all the similar torpedoes that became popular during the following decades. These globe torpedoes were made from interlocking cup sets or similar paper packages, much like the Globe Flash Salute, or cherry bomb. The manufacturers would fill the cup sets with gravel and explosive mixture and then glue the cups together. They finished the torpedoes by tumbling with an adhesive and either sawdust or circular paper punchings. The process is described in Davis's *Chemistry of Powder and Explosives*³ and in a brief essay by John Drewes, "Cherry Bombs & Silver Torpedoes."⁴ The exact formulae of the powders used in the torpedoes were generally closely held trade secrets. The compositions listed below come from anonymous sources within the fireworks industry. These torpedo mixtures are less dangerous than the older Armstrong's mixture. Still, these mixtures are necessarily quite sensitive to shock and friction and must be handled with extreme caution in the smallest practical quantities.

The explosive powder used in the old globe torpedoes, so popular before their mid-'60s ban, was usually a mixture of potassium chlorate [$KClO_3$] and antimony sulfide [Sb_2S_3]. Sometimes the mixture was sensitized with sulfur, manganese dioxide, ferric oxide (red iron oxide) or even red phosphorus. However, the wise pyrotechnist strictly avoids mixtures containing phosphorus. Some torpedo formulae for torpedo powder follow.

Torpedo Powder

	(percentages by mass)		
	1	2	3
Potassium chlorate [$KClO_3$]	50%	49.5%	59%
Antimony trisulfide [Sb_2S_3] 350 mesh	50%	49.5%	30%
Aluminum, German [Al] -400 mesh flake			10%
Manganese dioxide [MnO_2]		1.0%	1.0%
Titanium (optional) [Ti] 40-60 mesh	+1.3%	1-3%	

All of these mixtures are very sensitive to friction and impact. They should be treated accordingly. A wise pyrotechnist mixes only in small quantities and stores no unused composition. The pyrotechnist should mix batches on sheets of acid-free paper using a soft, clean, artist's paintbrush used to stir the mixture. He covers the metal ferrule of the paintbrush with masking tape for added safety. Art supply stores stock a kind of Japanese art brush that is made of bamboo and fine animal hair. It has no metal parts at all; this kind of brush is nearly ideal for the purpose of dry-mixing sensitive mixtures. Washing the brush with real soap (not detergent) before use will reduce the static hazard, which can be substantial.

Globe torpedoes can be made on a small scale with a variation of the cherry bomb manufacturing method. The same cup sets are used. The artist begins with placing the bottom cups in the same kind of jig to hold them upright. Then he uses an ordinary powder reloading

scoop to place 1 cc of unpolished quartz aquarium gravel, about 10-15 mesh in size, in the bottom of the cup. Over this he places about .7 cc of the torpedo mix (or the components thereof). Then he paints the outside rim of the bottom cup with glue and slips the outside cup over the edge of the bottom (inside) cup, just as in cherry bomb making. After allowing the glue to dry thoroughly, he coats the torpedoes with hide glue. When this becomes quite tacky, the torpedoes are gently rolled in a coarse (15-20 mesh) sawdust and set aside to dry thoroughly. The next step is to briefly soak the torpedoes with a thick sodium silicate solution and roll them in a finer (20-30 mesh) sawdust. The pyrotechnist allows this to dry thoroughly and then coats once more with silicate solution. He then rolls the coated torpedoes in a mixture of fine (-30 mesh) sawdust and bright (i.e., fine flake -325 mesh) aluminum powder. Then he allows these to dry well. If a smooth finish is desired, he can tumble the torpedoes in a sawdust/aluminum mix with some large chunks of paraffin wax added. Globe torpedoes are ideal for slingshot use but deserve extra care in packaging, transportation, and use. Precautions for use should include gloves and eye protection—both for the person firing and spectators. Globe torpedoes always throw chunks of gravel and casting when they explode, so the pyrotechnist should be aware of the hazards. The best type of packaging is a sturdy cardboard box with coarse sawdust (such as 4-10 mesh) packing.

Another option to reduce the hazards of the experiment is to put the fuel and oxidizer components into the devices separately and then tumble the torpedoes in a barrel of sawdust to complete the mixing. This method avoids many hazards of working with the dry, mixed composition. A wet mixing method analogous to the method used to produce the Japanese cracker balls can also be adapted to produce globe torpedoes (see Chapter 12). This wet method is a safer way to make the globe torpedo than the methods using dry chemicals or dry composition. However, there is a trade-off in terms of the time required to complete this process—this method takes substantially longer. In the wet method the required gravel is thoroughly wetted with distilled water, and then the dry, sifted chemicals are added to the gravel one at a time until the gravel is coated with a wet slurry of composition. A good ratio of gravel to composition is 7:1 by

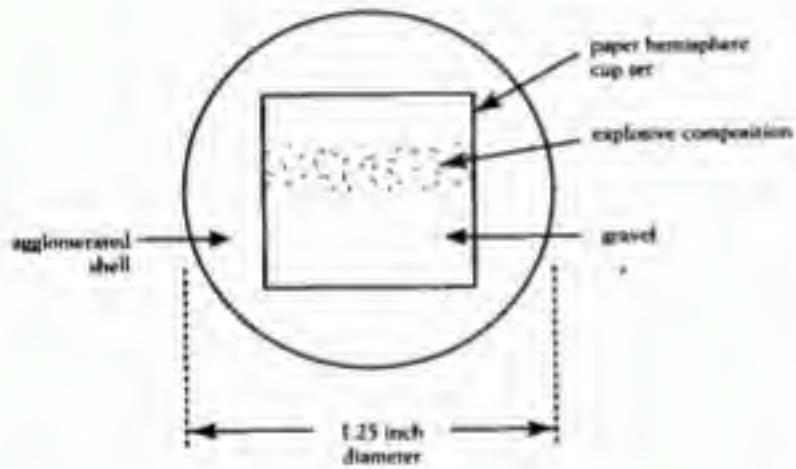
weight. A ratio higher in gravel will yield a less powerful version of the torpedo. Only the straight chlorate/antimony sulfide should be used, aluminum powder being strictly avoided in the wet mixing because of an increased likelihood of spontaneous combustion and subsequent explosion while drying. As with cracker balls, the bottom cups are filled well over the rims with the wet gravel/composition mixture, and then the top cups are glued on snugly.

These torpedoes should be wrapped in adhesive coated paper (paste wrapped) or in gummed paper tape, since the traditional agglomerated finish would interfere with the drying process by sealing in the moisture of the wet composition. Under ideal conditions (direct sunlight and low humidity), these torpedoes will be dry within a day or two. Otherwise drying will take longer, even up to a few weeks. When the torpedoes are completely dry, if they don't seem to function up to expectations, it is possible to add from .25 percent to .50 percent of finely powdered manganese dioxide to the next batch of mixture to speed up the reaction and lower the activation energy. Also, if the torpedoes seem too insensitive and will not fire except under great impact, they can be tumbled remotely, a few at a time, in a rock tumbler half filled with sawdust to increase the degree of admixture of the components. The wise pyrotechnist is aware, though, that the chances of unintended explosion during this tumbling are rather high. Therefore, risk is minimized by tumbling only a few devices at a time in a remote location where such an explosion would cause minimal damage.

ENDNOTES

1. George Washington Weingart. Pyrotechnics, second edition. (New York: Chemical Publishing, 1947) 174-175.
2. U.S. Patent #1,530,460 (1925).
3. Davis. Chemistry of Powder and Explosives. 108-110.
4. John Drewes, "Cherry Bombs and Silver Torpedoes." (New York: Empire BBS, 1987).

Globe Torpedo Diagram



The Cracker Ball



Back in the 1960s, the Japanese "cracker ball" or "ball type cap" was a popular torpedo firework in the United States. The ones I used to buy as a child were about $\frac{3}{4}$ inch in diameter or slightly more. These cracker balls were made of Japanese tissue paper twisted and rolled in several layers around a small core of gravel and an arsenic disulfide/potassium chlorate composition—what the Japanese call "red explosive composition." Actually, the color of the composition is a yellowish orange. The outside layers were colored with ink in bright colors: yellow, red, green, and purple. The finished cracker balls resembled Trix breakfast cereal—so much so that some kids ate some of the cracker balls and came down with arsenic poisoning. Hence the demise of the "cracker ball" in the United States. My friends and I used to shoot these great little torpedoes from slingshots against the brick wall of our school. Shooting cracker balls was all great fun, and altogether a fabulous, harmless way of venting our pent up frustrations and hostilities without hurting anyone or destroying anything.

Although the cracker ball is no longer available in this country, it is still possible to create something similar using the same formulation as in the original ones. Grown-up sized cracker balls can be created with ordinary cherry bomb cup sets.

Cracker Ball Composition

(parts by mass)

Potassium chlorate [KClO ₃]	2
Arsenic disulfide [As ₂ S ₄]	1
Water [H ₂ O]	as needed

The modern pyrotechnist begins by setting the bottom cups upright in a jig, just as for cherry bombs or globe torpedoes. The composition for the cracker balls is the tricky thing.¹ This "red explosive" has a reputation second only to Armstrong's mixture for sensitivity. Like Armstrong's mixture, cracker ball composition must be mixed wet, although the technique differs slightly. The same quartz aquarium gravel is used as for the globe torpedoes, but uncoated. For approximately two dozen "cracker balls" the hobbyist uses 60 grams of the gravel. He places the gravel in a disposable plastic container—a pint yogurt container works well. Next, he wets the gravel with a little distilled water, but not so much that a puddle will form in the bottom of the container. He stirs the gravel with a large wooden tongue depressor. Then he adds 2 grams of arsenic disulfide (realgar) and stir this mixture until the gravel is thoroughly coated with the wet realgar. The realgar needs to be a very fine powder, such as the Japanese pyro grade. Coarse-ground realgar will not perform adequately. Next, he adds 4 grams of slightly dampened potassium chlorate powder to the mixture and stirs until all the gravel is coated with a damp, homogenous mixture of realgar and chlorate. The composition is then ready to load.

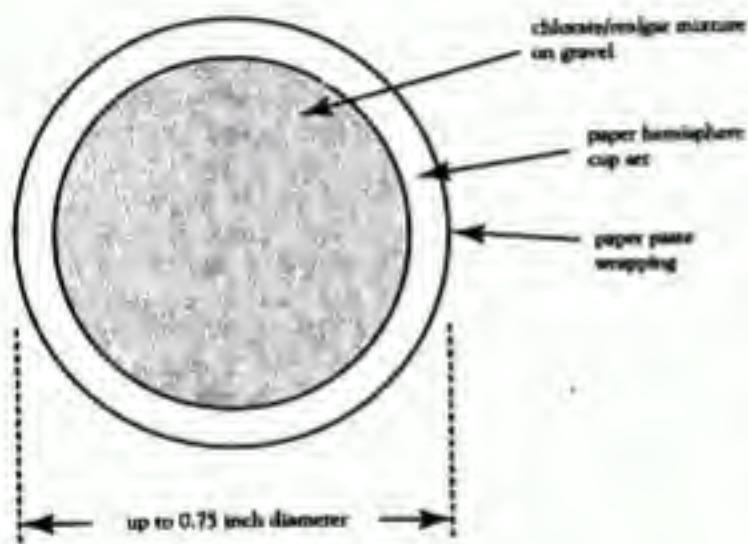
The artist fills the bottom halves of the cup sets with the damp composition and gravel mixture with a powder loading scoop. The

gravel should be heaped slightly above the edge of the bottom cup. Then he applies a line of glue around the outside of the bottom cup. He then places the top half of the cup over the bottom half, pressing down firmly so that the top compresses the gravel & composition into a tightly-packed mass. Next he covers the cracker ball with gummed paper tape. He can use lengths of tape 2 inches wide by 5 inches long, moistened with a wet towel (he avoids using his tongue around arsenic!). The cracker balls are rolled in the gummed tape, covering them with several layers of paper. This composition is very toxic, so the wise pyrotechnist will not clean the container when finished but simply dispose of it. When the cracker balls are dry—and this may take several days or even weeks, depending on the temperature, humidity, and so on—they put the old ones to shame.

ENDNOTES

1. Takeo Shijimizu, PhD. *Fireworks: The Art, Science, and Technique*. (Austin, TX: Pyrotechnics Publications, 1988) 275-276.

Cracker Ball Diagram



Chasers



One of the earliest known forms of firework was known in ancient China as a "mad rat." This was a small, rocketlike device that scuttled along the ground in an unpredictable zig-zag path. The modern whistling chaser and its relatives—have been perennially popular for close to a century. In form, the whistling chaser is a long convolute-wound tube filled with a pressed column of whistling compound topped off with an explosive charge and a paper cap or cork in the end.

The original whistling chasers were made with extremely sensitive picric acid salts that emitted shrill whistles accompanied by a tell-tale cloud of dense, black smoke. This shriek would be followed by an ear-splitting flash report. Later versions have used other compositions. For a time, a composition of gallic acid and potassium chlorate was prevalent. Then benzoate- or salicylate-based compositions using potassium perchlorate as an oxidizer became popular. Each step in this evolutionary process produced a mixture safer than the previous mixtures to load, store, and use. In recent years the Chinese have developed potassium perchlorate whistle compositions that use potassium acid phthalate as a fuel. All of these kinds of whistle compositions have found use in various whistling and exploding fireworks.

Each of these kinds of whistling compositions has its advantages and disadvantages. There seems

to be a trade-off between safety and effectiveness with these compositions, as with so many other pyrotechnic mixtures. One of the safest—and oddly enough, one that is very effective—is described below. The secret to the performance of this composition is the petroleum jelly that seals the particles of salicylate from humidity and at the same time aids as a lubricant when pressing the composition into tubes.

While any composition that whistles is both powerful and sensitive, the following mixture is less sensitive than most others. Potassium benzoate may be substituted for the sodium salicylate without any problem. One shortcoming of sodium salicylate-based whistle compositions is that they tend to be hygroscopic and fail to whistle when damp. If the pyrotechnist starts the following process with dry salicylate, this composition overcomes that problem.

The improved whistle composition formula is as follows.¹

Whistle Composition

(percentages by mass)

Potassium perchlorate [KClO ₄] 200 mesh powder	64%
Sodium salicylate [NaC ₇ H ₅ O ₃] 200 mesh powder	32%
Red iron oxide [Fe ₂ O ₃] fine powder	1%
Petroleum jelly	3%

The method of mixing is critical. The pyrotechnist first measures out the quantities of chemicals required. Both respirator and plastic gloves are necessary. He dissolves the petroleum jelly in four times its weight of toluene; it may help to melt the petroleum jelly

first. Of course, the heating of the petroleum jelly should be done away from the highly flammable toluene. He mixes together the sodium salicylate and the red iron oxide and sieves through a 20 mesh screen until evenly blended. Then he adds the petroleum jelly solution to the salicylate mixture and stirs with a wooden stirring stick (a wooden paint stirrer works well) until the mixture is homogenous. Finally, he adds the potassium perchlorate while stirring and stirs the entire mixture gently and thoroughly. This mixture is spread out on a stack of newspapers covered with brown kraft paper to dry overnight. He does this outside or in an outbuilding where no one will have to breathe the fumes from the evaporating toluene. Also, he watches out for lights and electrical sparks that could ignite toluene vapors, which are extremely flammable.

The next day, he gently sieves the mixture twice through a 40 mesh mixing sieve. Then he places the mixture in a paper bag to dry further for at least a week. Any solvent remaining in the mixture needs to evaporate before the mixture is pressed into whistles, or else the column of composition can crack as it dries, risking malfunction (explosion) of the whistle.

The wise pyrotechnist handles this mixture with care. It is both friction and shock sensitive, so it should never be rammed with a mallet, but only pressed by hand or with a press.

MAKING CHASERS

For good quality chasers, the pyrotechnist uses some special tubes and tools. First, he uses a tube either $\frac{5}{16}$ inch or $\frac{1}{2}$ inch inside diameter, made of high quality convolute-wound kraft paper. A set of special rammers is required that fits the inside of the tube snugly. These are made from polished brass or aluminum rod. One of the rods is cut off flat and polished smooth. The other is ground on the end into a cone or modified truncated cone shape. A nipple is required to support the tube during filling and also to produce a cavity at the front end of the tube to hold the report compound. A ramming nipple can be made from a block of wood and a dowel of a diameter to match the inside diameter of the whistle tube. A shal-

low hole can be drilled into the wood block with a drill press and then the dowel can be glued into the hole. For the $\frac{5}{8}$ -inch inside diameter by 4 $\frac{1}{4}$ inches long whistle tubes, a nipple 1 inch long is adequate to leave room for a report of about 5 grains—quite loud enough to alienate the neighbors.

First, the pyrotechnist places a tube on the nipple and uses a powder scoop to measure 1 cc of whistle composition powder into the tube. Then he takes the flat end rammer and puts it into the tube and resting on top of the composition. Then he places the whole arrangement under the arbor press and applies pressure to the rammer with the press. Unless the tubes are top quality, he needs to be very careful in order not to burst the tube with the pressure of the press, which can occur without much effort. He repeats this procedure once more with the flat end rammer and finishes by repeating the process with the conical end rammer. The conical end of this rammer leaves a greater surface area to burn than a flat rammer and gives the whistle extra thrust and therefore a better "chase." It also makes the whistle louder. He then removes the whistle from the nipple.

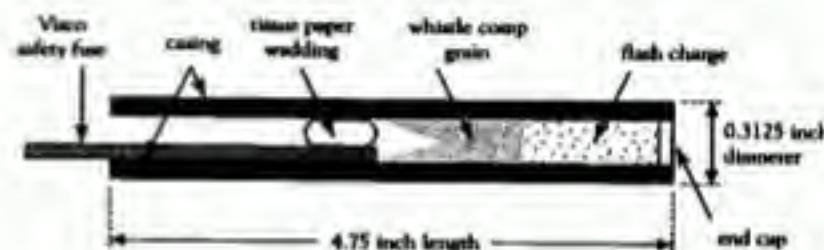
Next the report is added. This can be done by simply adding a plain firecracker into the end that was on the nipple. Or, to get fancier and louder, the artist can place a fused paper disk in the end of the tube that was on the nipple, glued right next to the end of the whistle composition. Then the remaining cavity is filled two-thirds full of flash and finished with a paper disk or plug glued on the end and covered with adhesive backed tape (e.g., kraft paper package sealing tape).

Finally, the pyrotechnist adds a piece of safety fuse, bent over on the end and placed next to the conical cavity of the whistle grain. This is secured with a wad of tissue paper in the tube, and is then ready to scream its heart out and terrify the local citizenry.

ENDNOTES

1. Barry Vreyens, "Screaming Rockets," *Bulletin of the Pyrotechnics Guild International* 70 (Indianapolis, IN: Pyrotechnics Guild International, 1990) 6.

Whistling Chaser Diagram



The Knallkörper



The Germans make an interesting variety of firecracker known as a Knallkörper or thunder-cracker. In design, it is somewhat similar to the British thunder flash, except that the timing fuse resembles the Italian spoolite fuse used for timing traditional aerial display shells. The Knallkörper is made from a convolute-wound paper tube about 3 inches long, $\frac{1}{4}$ inch inside diameter, and slightly less than $\frac{1}{2}$ inch outside diameter. One end of the tube is covered with a match head designed to be struck on a matchbook striker to ignite the device. If the tube is cut open, the observer can see that beneath the match head is a hard, pressed column of a black time delay composition. The rear of the column shows a cone shaped cavity that allows the time fuse to also act as a casing choke when the fuse burns through to the explosive charge. Past the time delay fuse column the tube contains about $\frac{1}{2}$ gram of potent German black aluminum-based flash composition. This is held in place on the opposite end of the tube by a small paper plug glued in place. The cracker is intended to be struck on a matchbook and thrown immediately. The time delay is usually about five to eight seconds before the cracker explodes with a loud report.

The pyrotechnist uses many of the same tools he uses to make the whistling chasers to make the Knallkörper, as well as the same tubes—a good choice is the $\frac{1}{4}$ -inch inside diameter tube and

matching rammer with the conical end. The tube must have a strong wall. The time delay composition the Germans use is called Glüsatz, which translates to English as "glow-fuse." The composition below was supplied by an anonymous German friend and is supposed to have come from one of the major German manufacturers. The pyrotechnist uses extra caution in handling this mixture because the barium nitrate makes it quite toxic—ingestion of less than a gram might be lethal.

Glüsatz:

(percentages by mass)

Barium nitrate $\text{Ba}(\text{NO}_3)_2$ fine powder	75.5 %
Charcoal AF	10%
Sulfur	10%
Meal powder	3%
Aero-Sil or Cab-O-Sil	1%
Methyl cellulose	0.5%

The Glüsatz is mixed in the following manner: First the pyrotechnist dissolves the methyl cellulose in an additional 6 percent of distilled water. Then he adds the finely powdered barium nitrate, stirring well. Next he adds the charcoal, stirring well, then the sulfur, all the while stirring. I stir this mixture until homogeneous, allow it to sit for an hour or so uncovered, then add the meal powder and stir. This mixture is screened twice through a 20 mesh sieve and allowed to dry partially. When dry to the touch, it can be rammed into the tubes.

The artist places the tube upright on a firm, smooth surface; a chunk of polished granite grave stone works well. He pours in an increment of time delay mix; $\frac{1}{2}$ of 1 cc is about right. Then he places the conical end rammer inside the tube. With a medium-sized rawhide mallet, he strikes several firm blows to consolidate the time delay fuse. The process is similar to that used for ramming spolette time fuses for aerial display shells.

Next step is to add a match strike composition. The following are two simple ones.

Match Composition

(percentages by mass)

	1	2
Potassium chlorate KClO_3	60%	50%
Antimony sulfide Sb_2S_3	20%	30%
Dextrine	20%	20%
Ground glass	+2%	

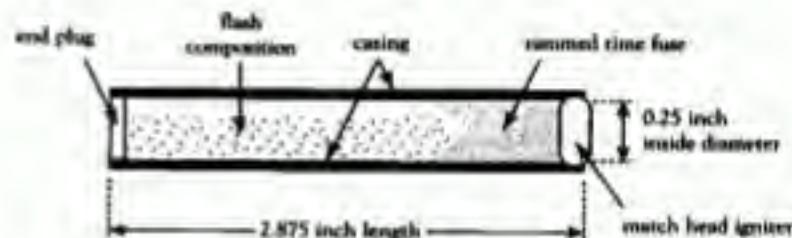
This composition is mixed wet with enough water to form a thick paste, similar in viscosity to oatmeal. It needs to be very sticky but not runny. The pyrotechnist applies it to the external end of the time fuse with a small paintbrush. Not much is required. Then he sets this aside to dry in the shade. Some like to add a protective nosing of tissue paper around the striker to prevent accidental friction and possibly accidental ignition of the finished cracker. At this point the artist can either fill the cracker or set the nearly ready knallkörper aside to be filled just prior to use. This may be a good precaution because of the chlorate-based ignition system. To fill the

cracker, the pyrotechnist uses a small paper funnel made of a conical paper cup to place about 1 cc of flash inside. He finishes the cracker by plugging the end with a glued-in, commercially made paper end plug. Alternatively, a paper disk and gummed paper tape could be used to the same end.

ENDNOTES

- Herbert Ellens, Military and Civilian Pyrotechnics, 1968. 355.

German Knallkorper Firecracker Diagram





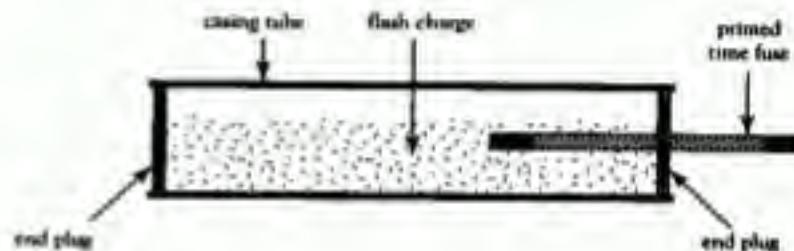
The Thunder Flash

The British were no slouches when it came to fireworks making back in the 50s either. The Waeco factory in Salisbury, now owned by Paine-Wessex, once made some great salutes known as Thunder Flashes. Similar in construction to some of the German firecrackers, these were made from a thin-walled parallel-wound paper tube of approximately $\frac{1}{4}$ inch inside diameter. The tube was plugged at one end with rammed clay and filled half full of flash; the other end was plugged with a piece of primed blasting fuse that fit the inside diameter of the tube, serving as both an ignition device and a tube plug. The fuse end was covered with a nosing of nitrate touch paper that needed only to be touched with a match to ignite it and the fuse underneath.

To make facsimiles of this device, the pyrotechnist can roll his own tubes on a former made of brass tubing from the local hobby supply shop. A former slightly less than $\frac{1}{4}$ inch outside diameter can be used to roll several paper tubes three inches long, as described in the chapter on Chinese firecrackers, but with the modification of "wet-rolling" the tubes. Wet-rolling produces a tube capable of holding a hard, rammed clay plug. The wet-rolling process consists of rolling the tubes with a small amount of adhesive applied all along the paper rather than only on the inside and outside layers. Either wallpaper paste or white glue will serve this

purpose. About five or six turns of heavy kraft paper would be sufficient to give a wall thickness that produces a tube with an outside diameter nearly twice the inside diameter. These tubes are allowed to dry thoroughly until they made a clinking sound when dropped on a hard surface. When the tubes are thoroughly dry, the artist plugs one end of each with clay, ramming the plug in firmly with a dowel and small mallet on a hard tabletop. Next he cuts lengths of Japanese time fuse 1 $\frac{1}{2}$ inches long and dips each end in a little black powder prime. When the fuse priming is quite dry, the pyrotechnist fills each tube half full of flash and inserts a fuse into the tube, gluing it in place with white glue. Next, he prepares nosings of Japanese tissue paper. Strips 1 $\frac{1}{2}$ inches wide and 3 inches long are cut against the grain of the paper, soaked in a solution of 10 percent potassium nitrate, and then dried. These nosing strips are glued in place over the fuse end of the salutes and twisted shut to form a protective covering for the fuses. The Japanese time fuse burns internally, and it is difficult to see whether or not it is burning. These thunder flashes can be some great little half-gram salutes.

Thunder Flash Diagram



The Booby Trap



Booby traps, also known as "pulling fireworks," are essentially cap-type devices that are actuated by pulling a string. These are often used as practical jokes and are also used as components of the ever popular "party poppers," the staples of New Year's Eve celebrations in the United States. In form, they resemble a small firecracker with a string running out from one or both ends. The most common ones are about 2 inches long and about $\frac{1}{8}$ inch in diameter. A piece of thin cotton cord that runs out both ends. The cord can be pulled by hand, or better yet, attached to a door and its jamb to explode when the door is opened.

The pyrotechnic hobbyist can make booby traps that are slightly larger than the commercial ones and have, more importantly, a longer, stronger cord. A piece of flax twine roughly 2 feet long works well for this purpose. For paper, a thick, handmade Japanese paper is best because of its high strength and neutral pH. The pyrotechnist cuts the paper for the case in a strip 2 inches wide and 6 inches long, the grain of the paper parallel to the short side. He dampens the paper slightly and glues it along the further edge. He makes a loop an inch and a half long in the center of the string and flattens it, laying the loop on the nearer short-cut edge of the paper strip. Now he makes some composition. The composition is very tricky stuff, which should be attempted only by the experienced pyrotechnist (who probably ought to know better anyhow).

This composition must be mixed and loaded in a wet state. This is an absolute must. Small quantities are recommended—a gram or two will make plenty of booby traps. Larger quantities present much greater risk to the maker and the user.

Booby Trap Composition¹

(percentages by mass)

Potassium chlorate [KCIO ₃]	67%
Antimony trisulfide [Sb ₂ S ₃]	25%
Red phosphorus [P]	6%
Dextrine	1%
Calcium carbonate [CaCO ₃]	1%

The pyrotechnist begins by measuring the antimony trisulfide, the phosphorus, and the dextrine into a small paper cup and adding enough distilled water to form a thin paste. Then in another cup he adds enough distilled water to the potassium chlorate to form a somewhat thicker paste. He allows both mixtures to stand for several minutes and ensures that both are thoroughly wetted. Then he mixes them together and stirs with a wooden stir stick until the mixture is homogenous. When the components are thoroughly mixed, he uses a small, laboratory-type spatula to scoop up the wet mixture and load the booby traps. A wooden coffee stirring stick will also suffice for the purpose.

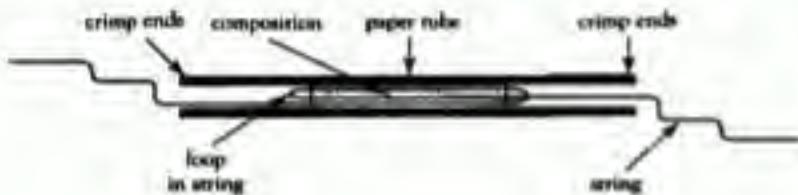
He smears a small quantity, approximately $\frac{1}{2}$ gram or less, over

the loop in the string. Then he rolls up the paper into a tight cylinder with the string loop and composition in the center. White glue or hide glue is applied to the outside edge of the paper, sealing the device. He sets the device aside to dry in a safe place, away from other fireworks and away from any flammable materials. When it is dry, he has a great little booby trap. Booby traps should be stored away from other pyrotechnic materials because there is always some risk of spontaneous combustion with potassium chlorate/phosphorus mixtures, even when buffered. Meticulous clean-up work with these little devils is required, because this composition, when dry, is one of the most sensitive of any mixture used in fireworks. This mixture is sensitive to heat, friction, impact, static electricity—some pyrotechnists swear that just a sidelong glance can explode cap compositions. Numerous accidents and fatalities have been attributed to the preparation and use of similar compositions, known in the trade as Armstrong's mixture or, more bluntly, "death mix."

ENDNOTES

- Shimizu, *Fireworks*, 275-276.

Booby Trap Diagram



The Triangle Cracker

The origin of the triangle cracker is obscure. This peculiar variety of firecracker is popular in Mexico, Central America, and on some of the Pacific islands. The devices I have seen vary in size from quite small, with loads of a tenth of a gram or less of powder, to monsters containing hundreds of grams of flash composition. The examples I have seen from Mexico usually range between a quarter of a gram and perhaps a gram or two of flash, or more of weaker mixtures.

The first triangle cracker I ever saw reminded me of the little love notes that my friends and I used to pass around when I was back in junior high school—made of ordinary note paper and folded into a triangular shape reminiscent of a folded U.S. flag.

Careful dissection revealed that the cracker was, indeed, folded much like those love notes of old. Inside the folds of paper was a small quantity of explosive powder. Sometimes this would be ordinary flash mixture, other times it might be a mealed black powder composition or something more exotic, such as perchlorate/benzoate whistle mix or a mixture of potassium chlorate with some organic fuel such as tannic acid. Invariably, the flash-filled crackers were the loudest, although presumably more expensive than some of the others to make. There was a fuse, usually crude and homemade. Often a cotton string boiled in potassium chlorate

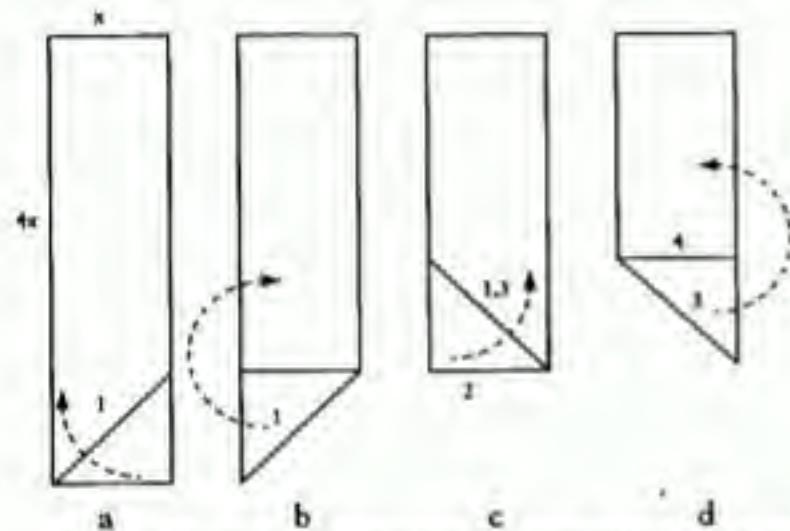


slurry served the purpose; other times a piece of thin black match was used. The crackers were usually pasted over with a single wrap of paste-soaked paper, which gave a little strength to the container and, more importantly, kept the cracker from coming apart during storage and transportation.

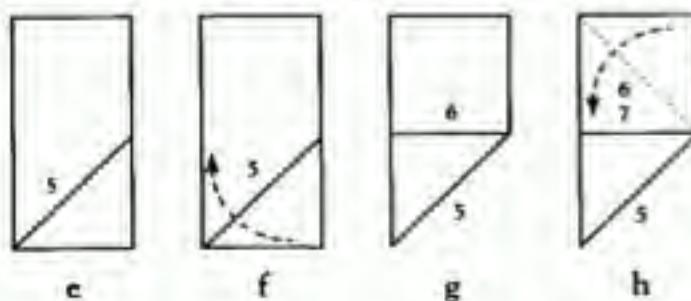
The pyrotechnic hobbyist can make these crackers easily. He begins with a square sheet of thin paper, four times as wide as the length of the short leg of the finished cracker. Newspaper works well for the purpose, but a lightweight kraft would probably work even better. Simple geometry reveals the ratio of legs to be $1:1:\sqrt{2}$ or about 5:5:7. A sheet 6 inches square will yield a cracker big enough to hold maybe a gram or so of composition. The pyrotechnist can use ordinary flash mix, but there is no reason why one couldn't use something else. Using this size as an example, he takes a sheet 6 inches square and folds it in half, lengthwise with the grain of the paper, and in half once more in the same direction. This produces a long rectangular sheet, 1 by 6 inches long. He cuts a length of visco safety fuse twice as long as the width of the paper, 3 inches in this case. He then folds the sheet from one end, bringing the bottom left corner over to the opposite side, creating a fold (fold #1) that measures 45 degrees, and an open edge of paper that lies perpendicular to the long edge of the paper strip. The artist then folds the paper over the perpendicular edge (fold #2), creating a triangular pocket of paper. He then folds the triangular pocket over the diagonal edge (fold #3), and again over the resulting perpendicular edge (fold #4), sealing the triangular pocket. Then he folds the paper over and over. He unfolds the paper back to the original triangular pocket. Into this pocket he scoops a small amount of powder and then inserts a length of safety fuse along one edge. He folds the paper over the pocket (folds #3, #4, and #5), sealing it shut. The sixth fold brings the last square of the remaining paper over the loaded triangle. Then, he folds the final edge into a triangle (fold #7), and carefully inserts it into the open flap of the outer layer of paper on the cracker, sealing the triangle shut. The artist soaks a piece of ordinary paper in wheat wallpaper paste and then folds it over the triangle. The device is allowed to dry. If a weaker composition, such as meal

powder, is used, additional paste wrapping is required. The layer(s) of pasted paper seals and stiffens the cracker, creating a strong and serviceable casing. That's all there is to it. The audible effect of the triangle cracker is favorably comparable with any tube firecracker or salute of comparable size.

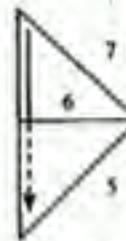
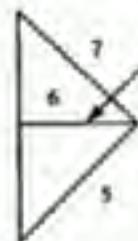
The Triangle Cracker Diagram



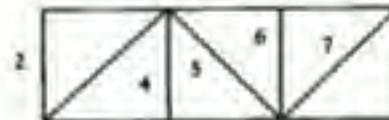
The triangle cracker is formed from a rectangular sheet of paper folded into repeating isosceles right triangles, much like flags are often folded. The first triangle, formed by fold 1 in diagram "a" sets the pattern for the rest. Repeat folds as shown in diagrams.



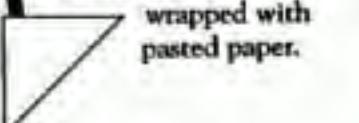
Flap into which tab formed by fold 7 is inserted.



The paper, folded as shown below, with first two folds in place is ready to load and fuse



Cracker is folded back up, along lines previously scored.





The Aerial Bomb

The aerial bomb is a firework that works much like a military mortar. The paper mortar tube fires a large salute straight up, which then explodes in midair at the apex of its trajectory. These great fireworks are Italian in origin. The Italians are second only to the Chinese in their long experience in and tradition of fireworks making—and perhaps first in level of skill attained in the pyrotechnic art. All modern aerial display shells are derived from Italian designs, probably even including the spherical Japanese shells. The aerial bomb was a popular fireworks item in the early 20th century in the United States and remains so despite the restrictions on the larger ones, which are all now considered class "B" display fireworks.

The aerial bomb consists of two basic component parts: the mortar and the salute shell. Traditionally, the mortar is a heavy walled paper tube mounted with glue into a wooden block. The wooden block has a shallow hole drilled in its center, the circumference of which corresponds closely to the outside diameter of the mortar tube. A fuse hole is drilled into the bottom of the tube just above the joint with the wooden base, through which a length of safety fuse is inserted. A charge of black powder provides the "lift" that propels the salute out of the mortar and also ignites the timing fuse of the salute. The salute itself is simply a sturdy container of paper or plastic that holds the charge

of flash report composition and the timing fuse and carries them up into the air where the salute explodes with a flash and report.

There are many variations on the basic design. The easiest way to make an aerial bomb is to order the prerolled, precut parts from a supplier and assemble them as intended by the parts manufacturer. However, given that parts like this may become less available as time passes, the pyrotechnic hobbyist may want to make his own or use scrounged or reused/recycled parts that will remain more widely available. He may be lucky enough to have access to a store that sells cast-off junk from many local businesses and industries. In such stores several sizes of paper tubes can often be found. If the artist finds two tubes that fit snugly one inside the other, he is several steps ahead in the game. If not, he can begin with whatever tube he has, decide whether he wants to use it as the salute or the mortar, and design the rest of the system from there.

Let's say, for example, the artist has some tubes 1 inch inside diameter with $\frac{1}{8}$ -inch-thick walls and 4 inches long. That gives a tube $1\frac{1}{4}$ inch outside diameter. He gets a block of scrap wood 3 inches square and $\frac{1}{8}$ inch thick from the workshop scrap bin. In the middle of the block he drills a $1\frac{1}{4}$ inch hole about $\frac{1}{4}$ inch deep with a drill press. He applies a liberal quantity of white glue inside the hole and sets the mortar tube in the hole. Alternatively, he can pour plaster of paris or tile grout in the hole and set the tube in that. When the mortar arrangement is dry, he bores a $\frac{1}{8}$ inch hole into the tube just above the baseline and above the glue. He places a length of safety fuse through that hole and the mortar is ready to load.

Now the pyrotechnist needs a salute to fire from the mortar. If he makes his own tube rather than using a commercially made tube, he starts by selecting a case forming rod that will give a finished tube with $\frac{1}{8}$ -inch-thick walls and a little room to spare, so he selects a rod $\frac{1}{8}$ inch thick. He uses the wet-rolled tube method to produce a tube 2 inches long and just under an inch outside diameter from 2-inch-wide, adhesive-backed kraft paper tape. When the tube has dried thoroughly, he places a round pasteboard plug in one end, through which he has drilled or punched two $\frac{1}{8}$ -inch holes and run two pieces of visco safety fuse. He glues the

plug in place securely with white glue, or a good quality PVA craft glue, and swabs some glue around the safety fuses where they join the plug. He allows the glue to dry thoroughly. Then the pyrotechnist inverts the salute case and fills it two-thirds full of flash composition. He places another, solid disk over the top and cements this firmly in place with glue. For added strength, he can "paste in" the salute by covering the whole thing (except the time fuses) with paste-soaked thin kraft paper (such as "lunch-bag" kraft). He cuts the paper in a 13-inch-long strip, 3 inches wide, against the grain of the paper. He paints the paper with paste until it is quite soaked but scrapes off any excess. Then he rolls the salute up in the pasted paper, folding the excess paper around the top and bottom of the salute as he goes, sealing and strengthening the top and bottom disks. The joint between the timing fuse(s) and the salute wall should be thoroughly sealed in, with pasted paper or tape covering a little of the fuse snugly.

Another approach to making the salute is to use a plastic container as the casing. One container that can work well is the plastic Easter egg found in stores before and, better yet, just after Easter. The artist drills a hole in the bottom half of the egg and inserts a length of good quality visco fuse through that hole. This he glues in with a good grade of plastic model cement and allows it to dry thoroughly. Next he fills the bottom half of the egg with flash and then glues on the top half. He must be careful not to get any flash into the joint between the two halves of the egg because of possible ignition of the mixture by friction. He finishes the salute by covering it with dampened gummed paper tape. One length of tape goes around the joint between the two eggs to seal it. Then several lengths are wrapped around the egg vertically. Two or three layers of paper tape are usually sufficient. The tape should cover the joint between the time fuse and the egg shell, sealing and reinforcing the joint. Other plastic containers are said to work well. One hobbyist recommends the plastic containers used for 35mm photographic film. The wise pyrotechnist experiments carefully!

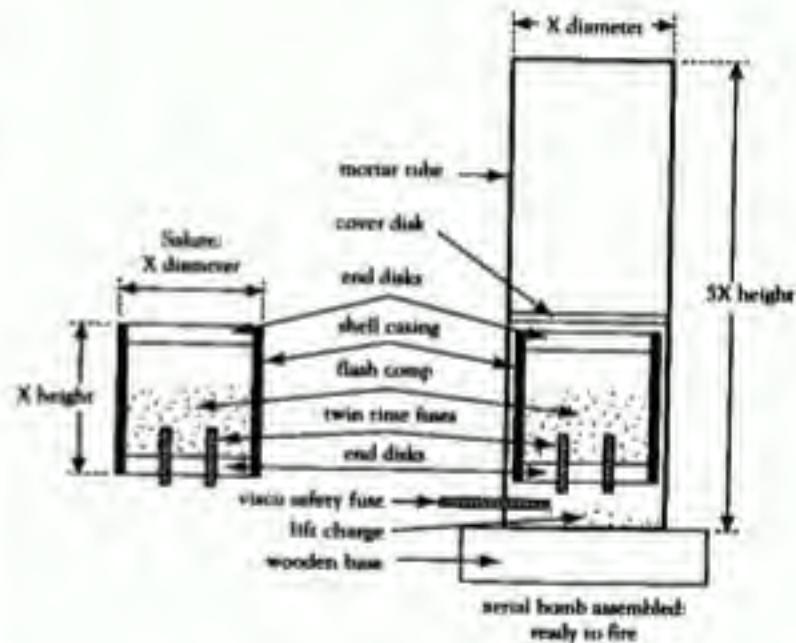
Of course, if commercially made tubes and plugs are available, the job is infinitely easier, if not as much fun. With commercial

tubes and plugs, often the pasting-in process can be skipped entirely if the plugs and fuses are securely glued in place. The larger the salute, though, the more advisable it is to paste in the device with a few layers of kraft—one layer per inch of salute diameter works well.

When the salute has dried thoroughly, the pyrotechnist places a teaspoon or so of black powder "lift" into the mouth of the mortar and drops the salute in on top of that, fused side down. The amount of lift required varies with the size of the shell and length of the mortar. The wise pyro always makes certain that there is no more than just a little space between the salute and the inside of the mortar—too great a gap will lessen the compression and cause the device to ascend poorly. Finally, he places a thin, 1-inch-diameter pasteboard disk on top of the salute to seal everything in and provide better compression on firing.

A well-made aerial bomb will certainly impress one's friends and just as certainly irritate the neighbors to no end. However, this is not the last word on the aerial salute; it is just a method that has worked for one experienced pyrotechnist. With this device, as with others, he always exercises due caution, especially when testing new and unproven designs. A couple of well-placed sandbags around the base of the aerial bomb will help ensure that the mortar does not tip over from recoil when firing. Remember, the wise pyrotechnist never puts his face, or any other body part, over the business end of a loaded mortar.

Aerial Bomb Diagram



Dimensions of the aerial bomb fireworks vary considerably. However, the length of the mortar is usually four to five times the outside diameter of the salute shell.

Glossary



Brisance—A measure of the velocity and strength of the shock wave produced by an explosive agent; that is, its shattering power. Generally "low explosives" such as black powder have less brisance than "high explosives" such as TNT. Photoflash compositions fall somewhere in between these: technically they are at the high end of the "low explosive" range, but legally in the United States, they are considered "high explosives."

Critical Mass—The mass of a particular composition that will explode unconfined upon ignition. The critical mass of any composition may vary depending on several factors, including ambient air pressure, degree of homogeneity of the composition, and source of ignition. In all cases the critical mass figure represents an approximation rather than an exact figure.

Cross-Matching—A method of increasing the reliability of time fuse ignition by puncturing both ends of the time fuse with a hollow punch through the powder core and then inserting into the hole a short length of black match fuse or Thermolite igniter cord.

Deflagration—A process of rapid burning, which may or may not be explosive in character.

Detonation—An explosive process characterized by a very rapid reaction moving through the explosive substance, usually at thousands of meters per second. Detonation is characteristic of true high explosives, whereas deflagration is characteristic of low explosives.

Electric match—Commonly known in pyrotechnic parlance as squibs, electric matches are devices used to ignite fuses or pyrotechnic mixtures by means of an electrical current.

Fuel—A pyrotechnic fuel is a chemical or substance that performs the reduction phase of a pyrotechnic chemical reaction. Usually such a reaction is characterized by binding with oxygen, liberating heat and light in the process. Typical examples of pyrotechnic fuels are aluminum, charcoal, and sodium salicylate.

Grain—The word "grain" in pyrotechnic parlance can refer to several dissimilar things or qualities. First, the grain of paper refers to the direction in which most of the paper fibers lie in a piece of paper. This can usually be determined by wetting one side of a sample piece and seeing which way the paper curls; it will usually curl against the grain, so that the paper forms a cylinder, the edge of which runs parallel to the grain. Second, a grain is a term of antiquated weight measure still used in some pyrotechnic legislation. This kind of grain is equivalent to approximately 65 milligrams metric. Third, the word grain can be used to refer to a pressed column of pyrotechnic composition, as in a rocket propellant grain.

Kraft paper—Technically the term kraft refers to nearly all machine made wood pulp papers. However, in practice the term kraft paper refers to a variety of crude, usually brown paper without sizing that is used to produce brown paper bags, cardboard, and paper package sealing tape.

Mass—A measurement of the amount of matter in a system (e.g., an object or a pile of powder) that is measured as weight on a bal-

ance scale. For practical purposes, it is the same as weight. However, for a better explanation of the concept, consult a basic text on chemistry or physics.

Oxidizer—An oxidizer is a chemical that performs the oxidation phase of an oxidation/reduction reaction. In pyrotechny this usually means that the oxidizer breaks down liberating oxygen, which feeds the combustion of the fuel component(s) in a composition. Typical pyrotechnic oxidizers include potassium nitrate, potassium chlorate, and potassium perchlorate.

Parallel-wound tube—A paper tube that is wound with layers of paper parallel to each other. Usually such a tube is wound around a former with the grain of the paper parallel to the length of the former, but this is not always so. The strongest parallel-wound tubes are wound with the grain of the paper at right angles to the former. Usually parallel-wound tubes are used in pyrotechnics only where a tube of great strength is required, such as in spoollette time fuses and rocket motor tubes.

Pasteboard—A single-ply cardboard such as that commonly used in breakfast cereal boxes.

Pyrotechnician—A term often used by the uninitiated to refer to a pyrotechnist. Often the word "pyrotechnician," is sneered, with the nose elevated, much as someone might use the term, "carny," to refer to the operator of a traveling carnival.

Pyrotechnist—Informally known as "pyros" among themselves, "pyrotechnists" practice the art of pyrotechnics, whether as the makers of fireworks, or merely as those who appreciate the art. Outsiders often refer to pyrotechnists as "pyrotechnicians."

Pyrotechny—A term that is synonymous with the term "pyrotechnics" but has an older and more distinguished linguistic and cultural heritage.

Report—Any audible explosion.

Salute—In pyrotechnics, "salute" refers to any large firecracker or to any aerial shell whose primary function is to produce a loud report.

Spiral-wound tube—A tube made from two or more layers of paper wound spirally around a former by a special tube-making machine. Spiral-wound tubes are usually weaker than parallel wound tubes but cheaper and safer to use for many exploding fireworks applications.

Spollette—A kind of timing fuse invented by the Italian pyrotechnists consisting of black powder rammed into a strong paper tube and capable of very precise timing for aerial effects.

Squib—1) A small rocket motor designed to fly both close to ground level or and in an unpredictable direction. 2) a word synonymous with electric match. 3) A word used to designate any of a class of small, electrically initiated explosive devices such as those that are used in the special effects industry. These squibs are different than electric matches.

Star—A pellet or ball of solidified pyrotechnic composition whose primary function is to produce a colored flame, or sometimes a report (for example, a "dragon's egg"). Stars produce the colored lights characteristic of most aerial display shells in public fireworks displays.

Timing fuse—A fuse used in an aerial display shell to time the delay from when the shell is fired from the mortar until it ignites overhead. At present the popular varieties of timing fuse in the United States include 1) Japanese time fuse, 2) Rozzi time fuse, and 3) handmade "spollette fuses" consisting of meal powder rammed very solidly into special, thick-walled convolute-wound tubes.

Torpedo—In fireworks parlance, any kind of firecracker-like device designed to explode on impact rather than by ignition with a flame.

Touch paper—A nitrated paper commonly used in British fireworks to aid ignition of fireworks, either in conjunction with or in place of a safety fuse.

Visco fuse—Visco safety fuse is a type of fuse used in fireworks that is made mechanically by winding a cover of thread around a black powder core. This core is then coated with one or more layers of nitrocellulose lacquer ("visco" is a trade name for nitrocellulose lacquer) to protect and seal the powder core. High-quality visco fuse has two or more layers of nitrocellulose lacquer coating ("double-coated") and an evenly distributed powder train composed of high-quality black powder. Poor quality visco may have only a single layer of lacquer and/or a poor-quality powder core.

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Further Reading



When one is just starting out in fireworks, one major problem can be just sorting out the good literature from the bad. There is plenty of both out there, and I've seen and read most of each that has come out in the English language over the past 20 years. The following is a list of publications relating to fireworks recommended for accuracy, clarity, and straightforwardness. Availability may be sporadic, but the fruits of the search can be worthwhile.

ATF-Explosives Laws and Regulations. This is an official government publication that covers U.S. federal laws relating to manufacture, use, storage, and transfer of explosive materials. It is handy not only as a guide to the law, but as a source of information about safe storage procedures for high-energy materials. Available from regional offices of the ATF or the following address:

Bureau of Alcohol, Tobacco, and Firearms
Department of the Treasury
P.O. Box 189
Washington, D.C. 20044-0189

American Fireworks News. This is a monthly newsletter published by a dedicated fireworks professional featuring many interesting and some not-so-interesting articles on fireworks. It also has the

best, most current classified advertisements for books, supplies, collectibles, and more. Edited by John Drewes, published by Rex E. & S.P. Co., HC67 Box 30, Dingman's Ferry, PA 18328. ISSN 8755-3163.

Bulletin of the Pyrotechnics Guild International. This is a quarterly bulletin issued to all members of the Pyrotechnics Guild International who have paid their annual dues. As of March 1996, contact Ed Vanasek, PGI Treasurer, 18021 Baseline Ave., Jordan, MN 55352.

Chemistry of Pyrotechnics, by John Conkling, PhD. This is a textbook covering basics of pyrotechnic chemistry. It is the most recent academic text covering the subject of fireworks chemistry. The price is a bit hefty at \$50, but it is a good, basic reference on pyrotechnic chemistry. Published by Marcel Dekker of New York, 1985. ISBN 0-8247-7443-4

Fireworks, edited by John F. Bennett. *Fireworks* is a magazine for fireworks aficionados that is published in the UK twice yearly. In the United States, *Fireworks* can be obtained through American Fireworks News, Star Route Box 30, Dingman's Ferry, PA 18328. In the UK, write to J.F. Bennett, 68 Ridgewood Gardens, Bexhill-on-Sea, E. Sussex TN40 1TS.

Pyro-Fax, edited by Dennis Manochio, Jr. *Pyro-Fax* is an irregular periodical dedicated to fireworks history and focusing largely on material of interest to collectors of fireworks-related antiques and collectibles. *Pyro-Fax* is a publication of the Fireworks Americana Museum, P.O. Box 2010, Saratoga, CA 95070.

Pyrotechnica, edited by Robert Cardwell. *Pyrotechnica* is a sporadically published scholarly journal dealing with fireworks chemistry, history, and technology. This is a top-notch publication, the only scholarly journal dealing with civilian pyrotechnics in the English language. Single-issue prices now run around \$25, and the

price is well deserved. Available from Robert Cardwell, 2302 Tower Drive, Austin, TX 78703. ISSN 0272-6521.

The Pyrotechnist's Treasury, by Thomas Kentish, this late 19th-century book gives excellent descriptions and drawings of many kinds of fireworks. However, many formulations given should be considered critically, especially colored flame compositions using salts of mercury and other toxic materials. Available at present from American Fireworks News, Star Route Box 30, Dingman's Ferry, PA 18328.

Resources: Chemicals and Supplies



American Visco Fuse Company
11984 Telegraph Road
Carleton, MI 48117
visco safety fuse manufacturer and distributor

Firefox Enterprises
P.O. Box 5366
Pocatello, ID 83202
chemicals, fuse, supplies, retail

Impulse Reactions
P.O. Box 61342
Seattle, WA 98121
chemicals, supplies, and tooling for fireworks

Service Chemical, Inc.
2651 Penn Ave.
Hatfield, PA 19440
chemicals, wholesale only

Smith Wholesale Fireworks
RR2 Box 287
Springfield, IL 62707
chemicals, fuse, consumer and display fireworks

Tread Corporation
P.O. Box 13207
Roanoke, VA 24032
storage magazines suitable for fireworks

Big Bang Pyrotechnics

Westwood Supply Co.
P.O. Box 246
Alden, NY 14004
chemicals, supplies, and safety fuse, retail



Internet Resources

Fireworks enthusiasts with access to the Internet can find a wealth of good information, as well as a lot of junk on the Net. Some of the sites listed below may be of interest.

USENET NEWS GROUPS

rec.pyrotechnics

alt.engr.explosives

These Usenet News Groups are long-established as these groups go. However, anyone logging in to either should be aware that the signal-to-noise ratio is pretty low, that is to say, probably 90 percent \pm 5 percent of what one sees on these groups is questionable information at best, and often deadly inaccurate and misleading. The FAQ file of *rec.pyrotechnics* is reasonably accurate.

WEB PAGES

Pyrotechnically oriented World Wide Web pages can be accessed at the following URL addresses:

<http://mercury.aichem.arizona.edu/~tip/pyro.html>

<http://tad1.cit.cornell.edu/Tom/CA/cpaHome.html>

<http://www.primenet.com/~pyro/>

Dominated by urban sprawl and various government policies to boil down the nation's open space, forests and rivers, Americans have become increasingly isolated from the natural world. In *The Last Great Places*, author and environmentalist Michael T. Smith explores the physical and spiritual benefits of getting away from it all. He shows how the natural environment can expand our minds, strengthen our bodies, and renew our spirits. This book reveals the beauty of the natural world and the ways in which we can well change the way we experience it.

Last year saw great concern over the economy, the health care system, and the safety of our food. Now, according to author Michael T. Smith, each of us must take personal responsibility for saving the environment. As a result, he offers readers a guide to the natural world that emphasizes the importance of personal action and the power of individual choice.

In addition to writing columns, Jason Lammert has written hypertextual programs for the Internet background. His most recent book is *Explorations of Home*. Jason currently resides in Massachusetts. Lots of his free time is spent with his wife, Elizabeth, and their two sons, Matt and Peter, who are ages 10 and 12. Jason also likes to travel, play golf, and go fly-fishing. In his spare time, Jason enjoys reading, listening to music, and watching football. Jason's e-mail address is jason@jason.com.

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ISBN 0-88359-359-8

